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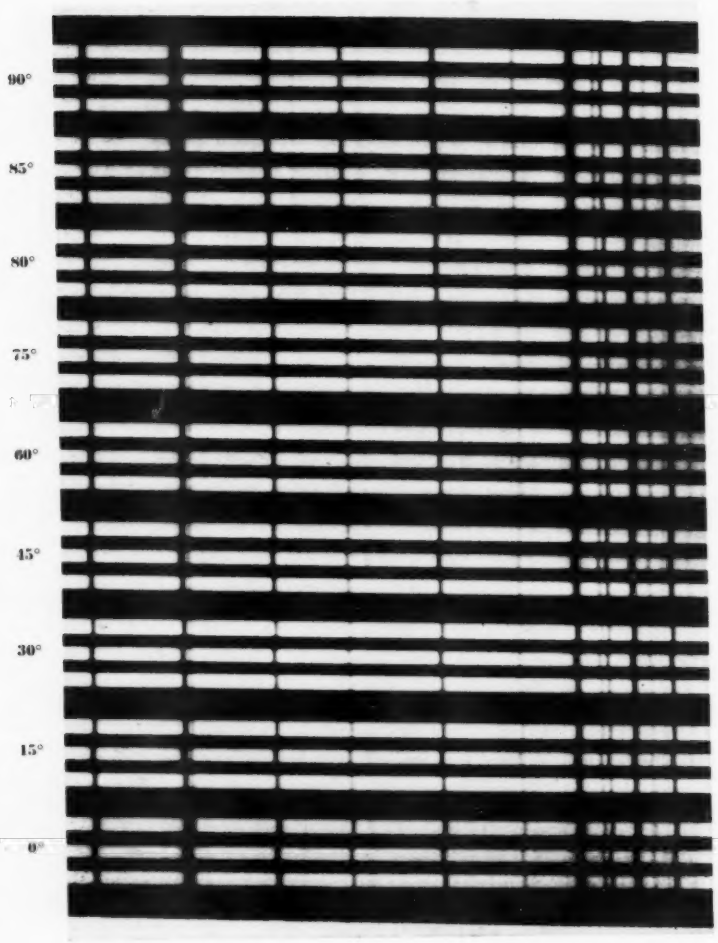
PLATE XIII



Solar rotation spectra, at various position angles from equator to poles, λ5569-λ5590, enlarged 3x.

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THE LAW OF THE SOLAR ROTATION

By RALPH E. DE LURY

(with Plate XIII)

THE rotation of the sun has been investigated from time to time for more than three centuries by telescopic observation of the direction and rate of progress of spots across the solar disc and by measurement of the periods required by the more enduring spots to complete one or more circuits of the sun. During the past sixty-five years systematic photography has supplemented and supplanted visual methods of observing the solar rotation from the changing position of the dark sunspots and the large bright spots or faculae; while in the last four decades spectrophotography of the sun in the light of selected radiations has enabled measurements of rotation to be made from the less stable calcium and hydrogen flocculi over intervals of a few days. Observation of these various solar markings has yielded information concerning the solar rotation within a restricted range of about 45° from the equator. The spectroscopic method of measuring rotational velocity from its displacement of the spectrum lines made possible observation at all latitudes. The first investigation by this method was completed fifty years ago and followed by two further series of direct visual measurements; and since then several observatories have been conducting extensive observations of the rotation of the sun with powerful spectroscopes and photographic recording of the spectra.

The results of the many investigations exhibit great variety, particularly those obtained by the spectroscopic method. Some of

the differences are due to various errors; but there is general agreement in revealing the presence of an intriguing relationship between angular velocity and latitude, though the formulae found to express the results vary considerably. A new formulation of the law of this relationship of decreasing angular velocity with increasing latitude, recently presented in brief outline,[1] harmonizes results whose actual similarity had been disguised in approximate representations by conventional formulae. These will be discussed generally after brief consideration of several factors which concern the accuracy of rotation determinations and the comparison of various series of observations.

Factors Relating to the Accuracy of Rotation Determinations

The following factors pertaining to the accuracy and differences in solar rotation results will be discussed briefly: the accuracy of the adopted position of the axis of rotation of the sun; the slight error due to elevation in determinations of spot positions; systematic errors in micrometer measurements of the displacements of spectrum lines; blended spectrum effects in lessening rotation displacements of spectrum lines; large accidental errors due to pore velocities; and errors resulting from approximate methods of calculation.

Direction of the solar axis of rotation. In Table I are given the early determinations by visual methods of the position of the axis of rotation along with the modern derivations from extensive photographic records. The angle between the ecliptic and solar equatorial planes is represented by I; while N is the longitude, epoch 1850, of the intersection of these planes at the ascending node (where the earth passes from the south to the north side of the solar equator). Included as an item of interest are the values of P, the "period of rotation" in days, derived by the earlier observers as an average of measurements of the differing values from sunspots at various latitudes. The means of the early determinations are given, followed by 1853-1861, based mainly on the more recent of the early observations, the values assumed by Carrington,[2] at the outset of his observations,

[1] *Trans. Roy. Soc. Can.*, 33, Sec. III, 1939.

[2] R. C. Carrington, Observation of the Spots on the Sun, 1853-1861.

his two derived sets of values from 86 series of observations and from 60 selected series, and his finally adopted direction in use today; the determinations of Spörer; and two determinations by Dyson and Maunder[3,4] from photographic records of the Greenwich and affiliated observatories.

TABLE I

	I ° ′	N, Epoch 1850 ° ′	P Days
Scheiner, 1611-1627	7 0	72 38	25.33
Cassini	7 30	72 34	.58
De la Lande	7 20	79 2	.42
Delambre	7 19	81 20	.01
Bianchi	7 14	70 55	.32
Laugier	7 9	75 16	.34
Petersen	6 51	73 37	.34
Böhm	6 57	77 1	.52
Kysaeus	6 38	76 46	25.09
Means	7 6	75 27	25.33
Carrington, 1853-1861,			
Assumed,	7 10	74 27	
Derived, 86 series,	7 14.5	73 46	
Derived, 60 series,	7 17.3	73 25	
Finally Adopted,	7 15	73 40	25.38
Spörer	6 57	74 23	25.23
Dyson and Maunder,			
Observations, 1878-1911,	7 11	73 54	
Observations, 1874-1912,	7 10.5	73 46.8	

The early observations seem to indicate a progressive lessening of the angle I of about 20′ a century. The mean of these values, however, is practically the same as the earliest one by Scheiner (about 1625), that of Carrington (1857) and that of the Greenwich investigators (say 1895). In view of this and the discrepant values of N in the early derivations the apparent variation in I may well be ascribed to error. There seems no sound reason for supposing that I varies at an appreciable rate. Giving the Greenwich determinations

[3,4] F. W. Dyson and E. W. Maunder, *Monthly Notices*, 72, 564-582, 1912; and 73, 673-687, 1913.

the greatest weight, the following values could be assigned to-day: *I*, 7°.2, and *N*, epoch 1850, 73°.8 (or 75°.2 for 1950). It seems certain that the direction of the solar axis of rotation adopted by Carrington and subsequent observers is not in error by a sufficient amount to have affected conclusions concerning the law of rotation.

Errors in Determinations of Spot Positions. Since observations of position of any solar marking, a sunspot umbra or penumbra, a facula or a flocculus, are made as projections on the general solar surface defined by the solar limb, differences in elevation of the various spots would introduce slight differences in the apparent rotational angle between successive observations and in estimations of latitude. In the case of the sunspot penumbra no allowance for this is necessary since it is bounded by the apparently normal solar surface. Corrections, involving estimates of their departures from the general solar surface, are applicable to measurements of position of umbrae, faculae and flocculi, some of them possibly of the order of one per cent. In some series of observations of the solar rotation this error has been avoided by measurements at the same longitude, that is after complete rotations.

Errors in micrometer measurements of spectrum line displacements. In the earliest observations of the solar rotation at Ottawa, 1909-1913, three strips of spectrum were photographed simultaneously, reflecting prisms directing through the slit of the spectrograph the light from a point within the advancing limb of the 227± mm. image of the solar disc for the middle strip, while similarly the pair of outside strips received their light from the corresponding diametrically opposite position within the receding limb. The 7 meter autocollimating grating spectrograph could be rotated on its nearly horizontal axis to photograph the limb spectra at the selected position angles from the solar equator to the poles, usually at intervals of 15° with the 80° and 85° positions included on many spectrograms, as in Plate XIII, which shows an enlargement of a small part of the spectrum within the Ottawa region, λ5500-λ5700, recorded on plate L885 (1)-(9), June 5, 1912, on which day the earth was in the solar equatorial plane. The relative displacement of a spectrum line in the opposite limb spectra varied from about one-tenth of a millimetre at the equator to about zero at the poles.

Since the spectroscopic determination of the rate of the solar rotation depends on the measurement of such small displacements of the spectrum lines, even minute systematic errors of measurement must be eliminated. Such errors were present in the earliest measurements made at Ottawa. Plates were measured on a Toepfer machine having a 300 mm. screw with polished end bearing held against a polished plate by a pulleyed weight fastened by a flexible cord to the 75 mm. nut to which was attached the plate-carrier. Settings were made by turning the screw to bring the image of a spectrum line under the spider line of the microscope, 4 settings on the line of the middle strip of spectrum followed by 2 settings on the line in each of the pair of outside strips. The selected list of lines was measured with the plate "violet left" and the measures repeated with plate "violet right". The following systematic differences were encountered:

(i) The measured displacement d' for the plate violet left was greater than the measured value d'' with the plate violet right;

(ii) Measured displacements by two observers differed in some cases by more than 0.002 mm.;

(iii) Lines of different intensity or character yielded different measured displacements.

As it was conceivable that some of these systematic differences might be due to physical factors associated with the problem of the solar rotation, the errors were investigated by measurement of mechanical displacement of the lines, the same for all lines.[5] Systematic differences persisted in these measurements, and it was concluded that they were micrometer errors with the possibility that in the differences between the measurements by two observers there might be an unconscious error due to prejudgement of what the displacement "ought to be". The writer avoided this pitfall by using a movable slotted mask through which only one strip of spectrum could be viewed during measurement and by computing the displacements after a series of plates had been measured.

The cause of the writer's systematic errors remained unknown for some years, when it was traced to the micrometer oil which caused the nut to move relatively to the screw by about 0.005 mm. in 3

[5] *Jour. Roy. Astron. Soc. Can.*, 5, 384-407, 1911.

minutes, the rate curve depending on the direction of screwing the nut in bringing the spectrum line's image to the spider line, that is, into or out of the nut, lifting or lowering the pulleyed weight.[6] Thus the duration of the measurement of a spectrum line was a factor affecting the three systematic errors (i), (ii) and (iii). It was possible with this knowledge to avoid the error and to eliminate it from earlier measurements. The error has probably affected the measurements of others, resulting in serious differences in the determinations of the solar rotation.

Effects of blended spectra on the measurements of the rotational displacements of spectrum lines. The measured value of the rotational displacement of a line in the spectrum from a point on the solar surface near the limb is lessened by weaker overlapping spectra from the following possible sources:

(f) matter foreign to the rotating solar surface falling into the sun at or nearly at right angles to the line of sight;

(s) particles between the sun and the telescope which scatter general sunlight, of which the terrestrial cirrus haze is prominent;

(t) the optical surfaces directing the sunlight to the slit of the spectroscope which scatter sunlight in varying amounts depending on the character of the plating of the telescope mirrors;

(σ) in multiple strip observations a small fraction of the spectrum light of another point of the sun may overlap an adjacent strip. Such overlapping may be due to multiple reflections between the slit and the reflecting prisms if mounted too far above it, multiple reflections from the surfaces of the collimating lens of the spectrograph, reflection from minute parts of the furrowed lines of the grating which may be inclined about one-tenth of a degree to the general direction of the grating lines, and temperature variations particularly the gradient between the exposed middle and masked outer portion of the grating, the effect being the same as though a trace of astigmatism spread out from one strip over adjacent strips.

Of these, (f) is hypothetical, although its assumption affords a possible explanation of certain solar phenomena; (s) is variable and present at all times; (t) is no doubt appreciable but would be lessened

[6] *Pub. Dom. Obs.*, 6, Pt. 1, 18-23, 1922.

by using aluminized mirrors; and (σ) is present in variable amounts usually weaker than (s).

For the past twenty years visual records of s+t+σ and of σ have accompanied observations of the solar rotation, the former by viewing the spectrum of a point outside the solar limb and the latter by occulting the illumination of the slit for one of the strips of spectrum and viewing the σ spectrum in its place, it being usually considerably weaker than the former.

To avoid as far as possible the lessening influence of the blended spectra, plates secured on the clearest days were selected for measurement. To obtain information which might lead to its elimination, observations were made of artificial blends of solar spectra from the centre of the disc with spectra from points around the solar limb. The measurements[7,8] of these revealed that the rotation displacements at the various position angles from the equator to 75° were reduced by the centre spectrum by approximately the same factor, and that the displacements of the weaker lines were lessened more than those of the stronger lines due no doubt to differences in the relative intensities and wavelengths of the spectrum lines in the two sources.

Such effects were found in the measurements of spectrograms of the solar rotation observed on days of different degrees of sky haziness; and similar results occuring in the Mt. Wilson measurements were suggested by the writer as due to a considerable strength of blended spectra.[9] This suggestion was received with skepticism at the time[10] and reiterated by the writer;[11] but now it is noted that a considerable effect of blended spectra, in which the σ component is prominent, is reported[12] as present in the Mt. Wilson observations referred to.

Fortunately, the difference between the measured values of lines of different intensity and its dependence on the strength of the blended

[7] *Jour. Roy. Astron. Soc. Can.*, 10, 201-219, 1916.

[8] *Pub. Dom. Obs.*, 6, Pt. 1, 41-55, 1924.

[9] *Jour. Roy. Astron. Soc. Can.*, 10, 345-357, 1916; also, *Astrophys. Jour.*, 44, 177-189, 1916.

[10] C. E. St. John and W. S. Adams, *Jour. Roy. Astron. Soc.*, 10, 552-555, 1916.

[11] *Ibid.*, 11, 23-24, 1917.

[12] *Trans. Int. Astron. Union*, 6, 65-66, 1938.

spectra affords a means of estimating a correcting factor for increasing the lessened values of the rotational displacements to their value devoid of the effects of blended spectra. Since the differences are small a large number of observations under varying degrees of sky haziness are required. The lines are divided into two groups of different intensity, and the observations are grouped with reference to large and small values of the solar rotation in the mean. Two curves are plotted for the two groups of lines, with the measured value of rotation as one ordinate and the difference between weak and strong lines as the other. These curves indicate an asymptote which intersects the velocity ordinate at the value freed from the influence of blended spectra. It is taken for granted that there is no actual difference in rotation for the lines in question since the evidence, that elevation differences in the solar atmosphere for the ordinary lines of the solar spectrum do not affect rotation, seems incontestable.[9]

Another method of eliminating the effect of blended spectra is to observe the rate of rotation at different distances from the limb along a parallel of latitude.[13] Blended spectra would reduce the values of the measurement of the solar rotation from the relatively weak limb spectrum considerably more than for the brighter region nearer the centre of the solar disc. Thus, from the cited note: 56 simultaneous observations at $\lambda 5600$ of limb points and points midway between limb and centre along a diameter of the solar disc during various degrees of haziness, yielded respectively for the equatorial velocity of rotation, 1.89 km. per sec. and 1.99 km. per sec. Haziness sufficient to reduce the limb values so much would also appreciably lessen the midway values, possibly by one per cent or more.

The effects of blended spectra may be avoided by using a proposed new method of observing rotational displacements of a spectrum line by passing a small rectangle of the continuous limb spectrum containing the line through a wedge-filter, or "neutral wedge", to a photo-electric cell thus generating an electric current which varies with the position of the line on the fixed wedge. By opposing to this varying current an unchanging current similarly generated from an adjacent equal area of the continuous spectrum free from lines, the magnitude

[13] *Pub. Am. Astron. Soc.*, 4, 19, 1918; *Jour. Roy. Astron. Soc. Can.*, 12, 442-446, 1918.

of the residual small current would be sensitive to the changes in wavelength of the solar limb line due to the rotation of the sun; while the blended spectrum line in unchanging position would not cause a variation in the photoelectric current and thus its effects would be eliminated. While the reflecting prism system supplying the limb light to the spectroscope is making a complete circuit of the limb, the intensity of the varying current generated, suitably amplified, could be recorded by galvanometer on one complete revolution of a photographic drum, thus permitting a rapid and repeated registration; and the rotation displacements of even such lines as H_ϵ could thus be determined using much greater dispersion than is employable in micrometer measurement in the usual way.

Accidental errors due to velocities in the solar pores. Frequently observations of the solar rotation made under presumably identical conditions, a minute apart, and measured in the same way, yield values of the solar rotation at the equator differing by 5 per cent or more. This is ascribable only to local convection on the solar surface. The slit of the spectroscope receives light from an area within the limb covering a few hundred thousand square kilometers in extent, and within this area there is chance for considerable range in convectional velocities. To explain these the writer advanced the hypothesis, supported by measurements of the penumbral displacements in sunspots at varying distances within the solar limb, that pores possessed a convective system similar to that in the penumbrae of sunspots.[14] The hypothesis also gave an explanation of the increase in the wavelengths of many spectrum lines at the solar limb, a point overlooked in a recent discussion of the various theories of the solar limb effect.[15] There is no reason to suppose that this source of variation in solar rotation measurements would seriously affect the average of a large series of observations.

Errors of approximate methods of computing solar rotation results. The approximate method, used in the earliest investigations, of treating the correction for the components of the earth's velocity as an additive term does not introduce very great errors for observations precisely on the limb of the sun from which nearly the full rotational

[14] *Pub. Am. Astron. Soc.*, 4, 149-150, 1920; 214-216, 1920; 258-259, 1921.
[15] A. Hunter, *Monthly Notices*, Roy. Astron. Soc., 94, 594-603, 1934.

velocity is observed; but for points a few per cent within the solar limb the error is serious at the higher latitudes where only small components of the rotational velocity fall along the line of sight. In 1911 the writer pointed to the need of adding the correction for the earth's velocity to the measured velocity and then multiplying the sum by

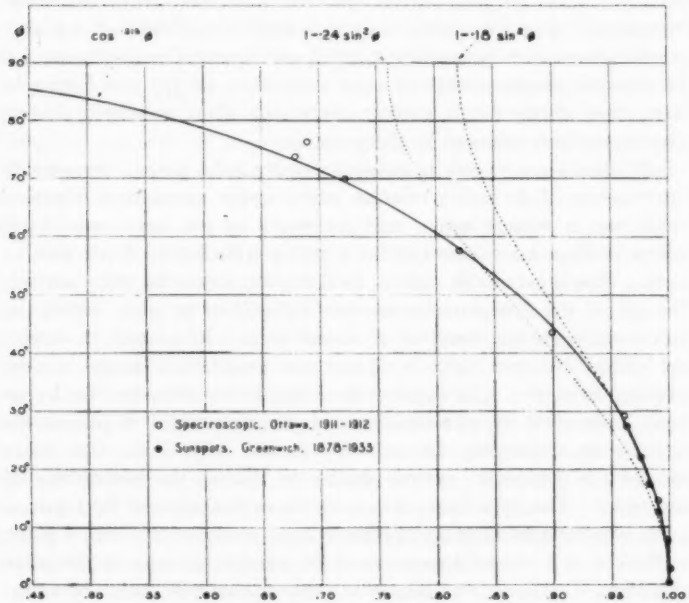

FIG. 1.—The Law of Solar Rotation. The proposed new form of the law, and alternative older forms, are compared with observations.

the secant of the angle between the line of sight and the direction of rotation; and also to the necessity of assigning the result to the latitude of observation and not to the higher latitude of the radial projection to the limb. Thus, the latitudes, ϕ, and the corresponding position angles, α, of plate L885, Fig. 1, for the points observed 2.5 per cent of the radius within the limb, from equator to poles, are:

α,	0°	15°	30°	45°	60°	75°	80°	85°	90°
ϕ,	0°.0	14°.6	29°.1	43°.5	57°.5	70°.2	73°.6	76°.0	76°.9

Tables greatly assist these computations.[16]

Relationship of the Solar Rotation to Latitude

Though the interesting discovery that a spot near the solar equator completed a rotation in less time than spots farther from the equator was made by Scheiner prior to 1630, it was not until after the middle of last century that the progressive decline in the angular velocity of the solar rotation with departure in latitude from the equator was definitely revealed. This was established by the investigations of Carrington who represented his observations[2] of the daily angular rotation at latitude ϕ by the formula,

$$14°.42 - 2°.75 \sin^{1.75} \phi, \qquad (1)$$

in deducing which he assumed that the rotational velocities were "equal at distances from the Equator, North or South". The angular velocities were observed to be slightly higher in the northern than in the southern hemisphere and they were closely reproduced by the expression,

$$14°.42 - 2°.75 \sin^{1.75} (\phi - 1°). \qquad (2)$$

Of this representation he remarks: "The errors are on the whole reduced by the additional assumption that the Equator of equal parallel rotation differs by one degree from the true Equator, and the solution is probably as good numerically as it is possible to find one, and very closely represents the total results of observation". Doubtless before adopting seven-fourths as the exponent of the sine of the latitude he had tried the small integral exponents; but later, Faye, using a value for the daily angular velocity at the equator 0°.08 smaller than Carrington's observed value, represented the results closely by the formula,

$$14°.37 - 3°.10 \sin^2 \phi. \qquad (3)$$

Theoretical considerations led Faye to suggest the exponent 2, and in the following forms it has usually been employed to represent the results of observations of the sun's rotation, A_0 being written for the daily equatorial angular velocity:

[16] *Pub. Dom. Obs.*, 6, 57-67, 1931; 71-84, 1935.

$$A_0 - B \sin^2\phi, \text{ or } A_0 - B + B \cos^2\phi. \quad (4)$$

The results obtained by Carrington stimulated work on the theoretical investigation of the problem of the solar rotation and several complicated formulae based on more or less plausible assumptions, were suggested. Besides that of Faye, the following simple formula found by Spörer to represent his observations has been applied by others to represent their results:

$$A_0 - B' + B' \cos\phi. \quad (5)$$

In these and subsequent determinations from sunspot observations the values of A_0 fall in a narrow range and the measurements of faculae and flocculi are slightly higher; while the low range in ϕ for all of these markings, permits with slight manipulation of A_0 the use of the various exponents and corresponding values of the B constants, (4) and (5) having been applied successfully to the same observations. These formulae do not reproduce so well the spectroscopic determinations which cover a wider range in values of ϕ, and the differences in the values of the constants at first sight appear to indicate different "laws" of the solar rotation. The question is clarified if the conventional formula (4) be written in the form,

$$A_0 (1 - b \sin^2\phi), \quad (6)$$

where as before A_0 is the equatorial angular velocity and b is the ratio B to A_0. In Table II, where the results of various determinations of the solar rotation from observations of sunspots, from faculae and flocculi, and from spectroscopic measurements are expressed in the form (6), it is seen that the mean value of the determinations from sunspots, faculae and flocculi is very closely, (see also Tables IIIa, IVa and Va)

$$A_0 (1 - 0.18 \sin^2\phi) \quad (6a)$$

while the mean formula for the spectroscopic measurements is,

$$A_0 (1 - 0.24 \sin^2\phi) \quad (6b)$$

The mean value of A_0 from the measurements of faculae and flocculi is greater than that derived from the sunspot observations possibly due to the projection error of measurement arising from the differences in elevation as previously mentioned; while that from the spectroscopic determinations is smaller than for sunspots due in part at least to the lessening influence of blended spectra.

TABLE II

Representations of Determinations of the Solar Rotation in the form $A_0 (1 - b \sin^2\phi)$

Sunspots			Faculae and Flocculi			Spectroscopic		
	A_0	b		A_0	b		A_0	b
	°			°			°	
Carrington	14.37	0.216	Chevalier	14.47	0.157	Dunér	14.81	0.284
Tisserand	14.29	.183	Kempf	14.43	.143	Halm	14.53	.172
Maunder	14.44	.148	Fox	14.56	.204	Adams	14.54	.240
Newton	14.37	.181	Newton	14.54	.193	Schlesinger	14.17	.240
						Storey and Wilson	14.75	.217
						Hubrecht	13.21	.229
						Plaskett and De Lury	14.21	.283
Means:	14°.37	0.182		14°.50	0.174		14°.32	0.238

From the new and more precise formulation[1] of the law of the solar rotation it is evident that the difference between (6a) and (6b) is due to the fact that the "constant" b, or B of (4), is a function of the latitude, and must have different values in the two ranges of latitude, $\pm$ 35° for solar spots and $\pm$ 75° for spectroscopic observations, in order to yield better approximations to the observed values.

As part of the process of revision of the early Ottawa observations of the solar rotation, errors due to the micrometer-oil and to blended spectra have been eliminated and estimated respectively for two almost identical series, totalling more than 40 observations, at λ5600 made in 1911 and 1912, in June and July when the earth was only slightly above the solar equator. The resulting values at the various latitudes could not be adequately represented by the conventional formula (4). They are closely reproduced by the new formula for the law of the solar rotation, namely, for angular velocity,

$$A = A_0 \cos^n\phi, \tag{7}$$

and for linear velocity,

$$V = V_0 \cos^{1+n}\phi, \tag{7a}$$

where n is approximately one-third and as before A_0 is the equatorial angular velocity, while V_0 is the equatorial linear velocity, the comparison of observed and computed values in km. per sec. being as follows (n=0.315):

ϕ	0°.3	14°.6	29°.2	43°.5	57°.4	70°.0	73°.9	76°.4	(90.0)
V obs.	1.955	1.874	1.642	1.277	0.864	0.483	0.369	0.318	0.003
Vcomp.	1.955	1.872	1.637	1.283	0.867	0.477	0.363	0.293	0.000
Diff.	.000	.002	.005	−.006	−.003	.006	.006	.025	.003

A reasonable correction of 3.5 per cent. for blended spectra, raises the value 1.955 km. per sec., of V_0, to equality with that derived from sunspots.

The value of n which represents these observations also closely reproduces the values derived from observations of recurrent sunspots made at Greenwich, 1878-1933. Values close to 0.35 for n represent the rotation measurements of faculae and flocculi by different observers, in which the average is taken of the results from both hemispheres. The velocities of rotation in the north and south hemispheres have been found to be different in several series of observations. Those of calcium flocculi measured by Fox are reproduced by n having the value 0.41 for the north hemisphere and 0.29 for the south hemisphere, with the value 0.35 for the mean.

Writing the expansion of (7), with 0.315 for n, in the form, $A=A_0\,[1-0.158\,\sin^2\phi\,(1+0.421\,\sin^2\phi+0.258\,\sin^4\phi+\ldots)]$, (8) the difference between (6a) and (6b), covering different ranges in ϕ, is at once apparent. Coincidence of (6a) and of (6b) with (7) or (8) occurs respectively for $\phi=32°$ and $\phi=55°$. While there is good agreement between the old and the new formulae over the small range of latitude to which (6a) applies, the approximation (6b) over the wider range of latitude, departs considerably from the new formula. Equations (6a), (6b) and (7) with 0.315 for n, are plotted in Fig. 1 along with Ottawa and Greenwich determinations.

Unfortunately, adequate determinations are lacking for comparison with the new formula for values of ϕ greater than 75°, where the expression departs radically from previous suppositions. Apart from

this, it is of theoretical interest to express the average law of the solar rotation as follows: *The angular velocity of a point on the surface of the sun is proportional to the cube root of its distance from the axis of rotation.*

Various series of determinations of the velocity of the solar rotation by different observers will be considered in the light of the new formulation.

Discussion of Solar Rotation Observations

In the present discussion the law of rotation of the solar surface expressed by equation (7) is adopted with 14°.37 for the equatorial velocity A_0 and 0.315 for the exponent n of the cosine. This is justified by the following facts: the Ottawa spectroscopic observations freed from systematic errors are closely represented by this formula and not by the conventional formulae; the formula satisfactorily explains the difference between the expressions (6a) and (6b) representing the average determinations of rotation from the various species of solar spots and from spectroscopic measurements respectively; and the extensive Greenwich determinations[17] from recurrent sunspots observed during five sunspot cycles, 1878-1933, are closely reproduced by the formula, as shown in Fig. 2. Failure of the adopted formula to represent closely any series of values of the solar rotation will be considered in relation to certain of the errors previously mentioned, and on the physical side, in some cases to systematic variation in measurements of rotational velocity dependent on the age of sunspots and groups.

The series of rotation values from observations of sunspots, groups of sunspots, faculae and flocculi assembled in Tables III, IV and V, will be discussed individually and collectively, followed by consideration of the spectroscopic determinations. In these Tables, along with the observed latitudes ϕ and the angles of rotation in one day A, are given interpolated values of the decimal parts of A at values of ϕ in multiples of 2°.5, desirable in determining comparable mean values. The extrapolated values are somewhat uncertain but they probably

[17](H. W. Newton), *Monthly Notices*, Roy. Astron. Soc., 85, 548-552, 1925; 95, 60-62, 1934.

do not modify the means seriously. The supplementary Tables IIIa, IVa and Va contain the constants of equation (6) derived from those of type (4) which had been found to represent the various series of results.

TABLE III.—Observed Daily Angle A of the Solar Rotation at Latitude ϕ

Sunspots									
Carrington 1853-1861		Spörer 1861-1893		Tisserand 1874-1875		Newton 1878-1933		Means 1853-1933	
ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ	A
°	°	°	°	°	°	°	°	°	°
0.0	14.45	0.0	.38	1.3	14.33	0.0	.39	0.3	14.39
2.5	.43	3.4	14.37	2.5	.33	2.8	14.39	2.8	.38
5.0	14.40	5.0	.32	6.3	14.33	5.0	.36	5.3	.35
7.5	.35	8.4	14.27	8.2	14.27	7.7	14.33	7.5	.31
10.0	14.29	10.0	.23	10.0	.22	10.0	.29	10.0	.26
12.5	.21	12.8	14.18	11.2	14.16	12.5	14.24	12.2	.20
15.0	14.13	15.0	.13	14.1	14.13	15.0	.18	14.8	.14
17.5	.06	17.3	14.08	16.3	14.10	17.3	14.12	17.1	.09
20.0	13.98	20.0	.00	19.2	14.05	20.0	.07	19.8	.03
22.5	.90	22.0	13.92	22.5	.99	22.0	14.01	22.3	13.96
25.0	13.82	25.0	.83	25.0	.91	25.0	.93	25.0	.87
27.5	.74	27.7	13.73	27.5	.82	27.3	13.84	27.5	.78
30.0	13.65	30.0	.64	30.0	.73	30.0	.74	30.0	.69
32.5	.55	32.5	.54	32.5	.62	32.5	.63	32.5	.59
35.0	13.43	35.0	.42	35.0	.50	35.0	.51	35.0	.47
17.5	14.03	17.6	14.00	17.4	14.03	17.5	14.07	17.5	14.03

TABLE IIIa

1858	1866	1875	1906	
A_ϕ = 14°.37	14°.37	14°.29	14°.37	14°.35
b = .216	.228	.183	.181	.198

TABLE IV.—Observed Daily Angle A of the Solar Rotation at Latitude ϕ

Sunspot Groups		Faculae							
Maunder 1879-1901		Stratonoff 1891-1894		Chevalier 1906-1908		Newton 1888-1923		Means 1879-1923	
ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ	A
°	°	°	°	°	°	°	°	°	°
0.0	14.44	0.0	.63	0.0	.51	0.0	.48	0.0	14.52
2.5	14.46	2.5	14.62	3.2	14.50	3.1	14.47	2.8	.51
5.0	14.45	5.0	.61	5.0	.47	5.0	.47	5.0	.50
7.5	14.40	7.5	14.61	7.9	14.44	7.2	14.47	7.5	.48
10.0	14.36	10.0	.47	10.0	.39	10.0	.45	10.0	.42
12.5	14.35	12.5	14.31	12.4	14.34	12.6	14.42	12.5	.36
15.0	14.33	15.0	.25	15.0	.29	15.0	.36	15.0	.31
17.5	14.28	17.5	14.18	17.3	14.24	17.6	14.29	17.5	.25
20.0	14.22	20.0	.19	20.0	.22	20.0	.22	20.0	.21
22.5	14.13	22.5	14.19	22.2	14.20	22.7	14.15	22.5	.17
25.0	14.05	25.0	.14	25.0	.10	25.0	.06	25.0	.09
27.5	13.99	27.5	14.08	26.8	14.00	27.3	13.97	27.3	.01
30.0	13.85	30.0	.83	30.0	.89	30.0	.82	30.0	13.85
32.5	.73	32.5	13.60	32.5	.78	33.9	13.67	32.9	.70
35.0	.62	35.0	.60	35.0	.66	35.0	.54	35.0	.61
37.5	.50	37.5	13.61	37.5	.53	37.1	13.41	37.4	.51
40.0	.38	40.0	.50	40.0	.40	40.0	.30	40.0	.40
						(42.5	.08)		
						(45.4	12.83)		
17.5	14.18	17.5	14.22	17.5	14.20	17.6	14.19	17.5	14.20
20.0	14.09	20.0	14.14	20.1	14.12	20.1	14.09	20.0	14.11

TABLE IVa

1886	1893	1907	1906	
A_0 = 14°.44	14°.56	14°.47	14°.54	14°.50
b = .148	.191	.157	.193	.172

TABLE V.—Observed Daily Angle A of the Solar Rotation at Latitude ϕ

Calcium Flocculi									
Hale and Fox 1893-1894		Hale 1906		Fox 1903-1908		Kempf 1906		Means 1893–1908	
ϕ	A	ϕ	A	ϕ	A	ϕ	A	ϕ	A
°	°	°	°	°	°	°	°	°	°
0.0	.67	0.0	14.42	0.0	.57	0.0	.49	0.0	14.54
2.5	14.66	2.5	.40	2.8	14.56	2.5	.48	2.6	.53
5.0	.59	5.0	14.38	5.0	.54	4.0	14.47	4.8	.50
7.5	14.52	7.5	.35	7.8	14.51	8.3	14.41	7.8	.47
10.0	.45	10.0	14.32	10.0	.45	10.9	14.33	10.2	.41
12.5	14.37	12.5	.30	12.6	14.38	13.4	14.28	12.8	.34
15.0	.30	15.0	14.28	15.0	.34	15.9	14.25	15.2	.30
17.5	14.22	17.5	.27	17.5	14.30	18.3	14.27	17.7	.25
20.0	.17	20.0	14.27	20.0	.21	20.8	14.16	20.2	.21
22.5	14.12	22.5	.22	22.2	14.12	22.5	.13	22.4	.16
25.0	.01	25.0	14.17	25.0	.06	25.1	14.08	25.0	.09
27.5	13.90	27.5	.08	27.2	13.98	27.5	.00	27.4	.00
30.0	.83	30.0	13.98	30.0	.87	31.2	13.90	30.3	13.87
32.5	13.76	32.5	.01	32.0	13.75	32.5	.79	32.4	.77
35.0	.63	35.0	14.04	35.0	.60	35.0	.68	35.0	.68
37.5	.50	37.5	.98	37.3	13.43	37.5	.56	37.5	.58
40.0	.40	40.0	13.92	40.0	.33	40.0	.43	40.0	.49
17.5	14.21	17.5	14.23	17.5	14.22	17.9	14.18	17.6	14.21
20.0	14.12	20.0	14.20	20.0	14.12	20.3	14.10	20.1	14.13

TABLE Va

1894	1906	1906	1906	
A_0 = 14°.56	14°.38	14°.56	14°.43	14°.48
b = .205	.081	.204	.143	.158

Rotation results from observations of sunspots. The averages of the angular velocities over the range of 35 degrees in latitude in the four series of observations in Table III fall within the narrow range of 0.5 per cent. Slight systematic differences in the rate of decline of angular velocity with increasing latitude are evident, and this is reflected in the values of b in Table IIIa. If expressed in the adopted form of equation (7) larger values of n are necessary to represent the results of Carrington and of Spörer; while the adopted value 0.315 fits the results of Tisserand and Newton. Thus, Carrington's results may be expressed approximately by,

$$14°.37(1-0.216\ \sin^2\phi),\ \text{or by}\ 14°.37\ \cos^{.345}\phi.$$

Spörer's values are those from his measurements of recurrent sunspots as assembled by Halm[18]; while the corresponding constants in Table IIIa refer to his determinations[19] for the interval 1861-1871 which he represented by the formula,

$$12°.73+1°.64\ \cos 2\phi,\ \textit{i.e.},\ 14°.37\ (1-0.228\ \sin^2\phi).$$

Equation (7) with 14°.34 as A and 0.36 as n represents his results fairly well. Using 14°.31 in the adopted formula expresses Tisserand's results, though the range in latitude is too small to indicate any variance in n from the adopted value 0.315.

Tisserand noted[20] that a new sunspot at latitude 21° exhibited the following daily motions for successive days: 15°.29, 14°.74, 14°.22, 14°.06, and two days later 13°.83; and in consequence his rotational observations were derived from recurrent sunspots. This phenomenon has been investigated extensively at Greenwich Observatory[21]; and it may well be a factor in the slight differences found in the rate of change of angular velocity with latitude.

It appears probable that the more rapid motion of incipient sunspots gradually settles down in about ten days to the normal velocity of the solar surface. This view is supported by the close agreement of the Ottawa spectroscopic observations of the rotation of the solar surface with Newton's Greenwich determinations from long-lived recurrent sunspots. The formulae for the five sunspot cycles covered

[18] J. Halm, *Astron. Nachrichten*, 173, 287-296, 1906.
[19] H. Spörer, *Pub. Astron. Gessellschaft*, 13, 151.
[20] F. Tisserand, *Comptes Rendus*, 82, 765, 1876.
[21] *Monthly Notices*, 85, 553-560, 1925.

by these determinations[17] are herewith quoted; and the equivalent expression of form (6) follows each:

1878-1888, $14°.36 - 2°.5 \sin^2\phi$; or, $14°.36(1 - 0.174 \sin^2\phi)$;
1889-1899, $14°.39 - 3°.0 \sin^2\phi$; or, $14°.39(1 - 0.208 \sin^2\phi)$;
1990-1913, $14°.39 - 2°.8 \sin^2\phi$; or, $14°.39(1 - 0.195 \sin^2\phi)$;
1914-1923, $14°.39 - 2°.6 \sin^2\phi$; or, $14°.39(1 - 0.181 \sin^2\phi)$;
1924-1933, $14°.37 - 3°.0 \sin^2\phi$; or, $14°.37(1 - 0.209 \sin^2\phi)$.

The mean latitudes and angular velocities for the five cycles are given in Table III; while the corresponding value of b in Table IIIa is derived from the formula representing the first four cycles as a group, namely,

1878-1923, $14°.37 - 2°.60 \sin^2\phi$; or, $14°.37(1 - 0.181 \sin^2\phi)$.

In the determination of the solar rotation from sunspots this formula must be assigned a relatively great weight. It is found to be practically equivalent (Fig. 2) to the adopted formula,

$$14°.37 \cos^{.315}\phi,$$

over the small range of latitude covered by the sunspot observations.

Rotation results from sunspot groups and faculae. In Table IV are assembled the mean angular velocities of the solar rotation derived by the Maunders from recurrent sunspot groups[22]; and from faculae by Stratonoff,[23] Chevalier[24] and Newton.[25]

As in the case of sunspots the rotational velocities from groups and faculae exhibit but slight variety in the four series of measurements, which yield an average a little more than 1 per cent greater than for sunspots. In the rates of decline of angular rotation with increasing latitude there are small differences as indicated by the different values of b in Table IVa. Facular elevation above the general solar surface no doubt results in slight over-estimates of latitude; and in the case of the day to day measurements of Stratonoff and Chevalier to slightly larger rotational values than in the observations of recurrent groups and faculae. Larger values of rotation for a group would result from the earlier disappearance of the following spots of the group and from facular masking of the near side of a

[22]E. W. and A. S. D. Maunder, *Monthly Notices*, 65, 813-825, 1905.
[23]W. Stratonoff, *Mémoires, Acad. Sci.*, St. Pétersbourg, 5, No. 11, 1896.
[24]S. Chevalier, *Annales, Observ. Astron.*, Zô-sè, 5, 61-85, 1911.
[25]H. W. Newton, *Monthly Notices*, 84, 431-442, 1924.

group on either side of the central meridian. From a large series of measurements of the centre of gravity of sunspot groups at various latitudes the Maunders derived for groups of short (6 to 7 days), medium (8 to 10 days), long (11 to 14 days) and recurrent duration, the mean daily sidereal motions of 14°.50, 14°.48, 14°.33 and 14°.29 respectively. On this account they used only recurrent groups in the results given in Table IV.

In the mean there is a slightly smaller rate of decline in angular rotation with increasing latitude for sunspot groups and faculae than for sunspots.

Rotation results from calcium flocculi. In Table V are shown rotation measurements from the motions of calcium flocculi from day to day, by Hale and Fox,[26] Hale,[27] Fox[28] and Kempf.[29]

In the mean the results for flocculi are practically the same as those derived from faculae and sunspot groups. The measurements were necessarily made of the motions of flocculi in a few days. The results of Hale show a rate of decline between latitudes 20° and 40° considerably less than the others. This is reflected by an abnormally small value of b in Table Va, deduced from the formula derived by Kempf. The average of the other three values of b does not differ much from the average b in Table IVa and is almost identical with the b for Newton's measurements of recurrent sunspots.

The mean velocity for flocculi over the range of 35° in latitude is about 1.3 per cent greater than for sunspots. The projection error due to elevation of the flocculi above the solar surface no doubt plays a part in this difference.

As previously mentioned the measurements of Fox reveal larger velocities for the southern than for the northern hemisphere. He has represented these observations closely by formulae of the usual type (4); and they are also closely reproduced by formula (7) with the exponent of the cosine 0.41 for the northern hemisphere and 0.29 for

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[26]G. E. Hale and P. Fox, The Rotation Period of the Sun, Carnegie Inst., Washington, Pub. No. 93, 1908.

[27]W. S. Adams and J. B. Lasby, An Investigation of the Rotation Period of the Sun, Carnegie Inst., Washington, Pub. No. 138, p. 118, 1911.

[28]Philip Fox, *Pub. Yerkes Observ.*, 3, Pt. 3, 1921.

[29]P. Kempf, *Pub. Astrophys. Observ.*, Potsdam, Nr. 71, 1916.

the southern with 0.35 for the mean. The results are well represented also with the one formula using 0.35 as exponent and $\phi + 2°$ in place of ϕ, thus,

$$14°.55 \cos^{.35}(\phi + 2).$$

A possible physical explanation of this peculiarity is that the spherical shell of the solar surface was, at the average time of the observations, 2° off centre to the north with reference to the rapidly rotating dense nucleus of the sun, or possibly that their axes were relatively tilted by 2°. The values computed by the various formulae are given in Table VI.

TABLE VI

Daily Rotation A at Latitude ϕ observed by Philip Fox from Calcium Flocculi; and Values derived from Various Formulae.

NORTHERN HEMISPHERE									Means
ϕ = ...	2.9	7.9	12.5	17.4	22.2	27.0	32.1	37.1	19.9
A = ...	14.58	14.51	14.33	14.24	14.05	13.88	13.63	13.26	14.06
(Fox): $14.556(1 - 0.237 \sin^2\phi)$:									
	14.55	14.49	14.40	14.25	14.06	13.85	13.58	13.30	14.06
Diff. = ...	.03	.02	−.07	−.01	−.01	.03	.05	−.04	.00
$14.543 \cos^{.41}\phi$:									
14.543	14.53	14.48	14.40	14.27	14.09	13.87	13.59	13.25	14.06
Diff. = ...	.05	.03	−.07	−.03	−.04	.01	.04	.01	.00
$14.543 \cos^{.35}(\phi + 2)$:									
14.543	14.53	14.47	14.38	14.25	14.08	13.88	13.62	13.31	14.06
Diff. = ...	.05	.04	−.05	−.01	−.03	.00	.01	−.05	.00

SOUTHERN HEMISPHERE									Means
ϕ = ...	−2.7	−7.7	−12.7	−17.6	−22.2	−27.3	−32.0	−37.0	−20.0
A = ...	14.53	14.52	14.43	14.35	14.19	14.05	13.88	13.65	14.20
(Fox): $14.551(1 - 0.165 \sin^2\phi)$:									
14.551	14.55	14.51	14.44	14.33	14.21	14.05	13.88	13.66	14.20
Diff. = ...	−.02	.01	−.01	.02	−.02	.00	.00	−.01	.00
$14.55 \cos^{.25}\phi$:									
14.550	14.55	14.51	14.45	14.35	14.23	14.06	13.87	13.61	14.20
Diff. = ...	−.02	.01	−.02	.00	−.04	−.01	.01	.04	.00
$14.55 \cos^{.35}(\phi + 2)$:									
14.550	14.55	14.53	14.46	14.36	14.23	14.05	13.84	13.55	14.20
Diff. = ...	−.02	−.01	−.03	−.01	−.04	.00	.04	.10	.00

BOTH HEMISPHERES									Means
ϕ = ...	2.8	7.8	12.6	17.5	22.2	27.2	32.0	37.3	19.9
A = ...	14.56	14.51	14.38	14.30	14.12	13.98	13.75	13.43	14.13
(Fox): $14.560(1 - 0.204 \sin^2\phi)$:									
14.560	14.55	14.51	14.42	14.29	14.14	13.94	13.72	13.47	14.13
Diff. = ...	.01	.00	−.04	.01	−.02	.04	.03	−.04	.00
$14.543 \cos^{.41}\phi$:									
14.543	14.54	14.50	14.42	14.30	14.16	13.96	13.73	13.42	14.13
Diff. = ...	.02	.01	−.04	.00	−.04	.02	.02	.01	.00

Chevalier's measurements of faculae, like those of Fox for calcium

flocculi, show larger velocities in the southern hemisphere than in the northern. They are approximately represented by the formula,

$$14°.50 \cos^{.35}\phi;$$

while cosine exponents of 0.37 and 0.29 reproduce fairly well the values in the northern and southern hemispheres respectively, using also 14°.50 as the equatorial velocity A_0.

In addition to the formula 14°.54—2°.8 $\sin^2\phi$ of type (4), Newton also represented his observations of recurrent faculae with better approximation by the formula,

$$14°.49 - 1°.78 \sin^2\phi - 3°.16 \sin^4\phi,$$

which resembles somewhat the expanded expression (8). His results are fairly closely reproduced by the expression,

$$14°.52 \cos^{.345}\phi.$$

The values derived by Kempf from his observations of calcium flocculi are approximately represented by,

$$14°.45 \cos^{.28}\phi,$$

though the range in latitude in the observations is rather small for a precise determination of the exponent.

Summarizing briefly the solar rotation results from spots of all kinds, it appears that:

1. The slight differences in measurements of each kind of solar marking are of accidental nature possibly due to variation of projection errors and the age effect on spot motions;

2. The variation in angular velocity over the small range of 35° or 40° in latitude covering most of the observations is expressed by formulae of types (4) and (7) with about the same degree of accuracy; and

3. Over the range of 35° in latitude the average velocity of rotation of sunspots is 0.9880 that from faculae and 0.9873 of that from calcium flocculi, or 0.9877 of the average velocity from groups, faculae and flocculi. The average velocity of sunspots is 0°.18 per day less than the average of faculae and flocculi, and this difference changes little with latitude.

Rotation results from spectroscopic measurements.—The Greenwich determinations of the solar rotation from observations of recurrent sunspots for the 55 year interval 1878-1933, previously quoted,

indicate that the equatorial velocity remained constant within the limits of minor possible errors at about 14°.37 per day, corresponding to a linear velocity of 2.02 km. per sec. Yet in the first 30 years of spectroscopic investigation of the problem, 1887-1917, the various series of observations yielded values of the equatorial velocity from 2.09 km. per sec. to 1.86 km. per sec. This variation of more than 10 per cent must be assigned to errors; and of the possible errors besetting the investigation, those due to micrometer measurement and blended spectra account mainly for the variations. Elimination of these errors from the early observations at Ottawa yields values in agreement with those derived from sunspots. It is presumed that the deviation of the results of other series of observations is due to these same errors. The Ottawa and Mount Wilson observations are lowered about 3 or 4 per cent by blended spectra; and it may be taken for granted that all other observations have suffered from this error.

Taking all of the spectroscopic determinations of the equatorial velocity observed from 1887 to 1917, at their face value, the writer showed[30] that there was a general relationship between their variations and the changes in solar radiation measurements expressed as percentages of the mean values for the stations, uncorrected for the atmosphere. The radiation percentages were in general higher at sunspot minima, and lower at sunspot maxima, due no doubt to haziness induced by sunspots; and also lower due to volcanic dust in 1902-3 and 1912-13. On the average a drop of 6 in the solar radiation percentages was accompanied by a lessening of 3 per cent in the spectroscopically measured solar equatorial velocities. This ratio is not likely precise in view of the possibilitiy of the presence of systematic micrometer errors in all of the measurements. The average of the writer's measurements of the equatorial velocity from 1909-1917 was about 1.96 km. per sec.; and the micrometer errors probably affected this by not more than 1 per cent. Since 1913 the Mount Wilson values average about the same as the Ottawa determinations; while the Edinburgh observations[31] for the interval 1914-1931 yielded a mean value of 1.97 km. per sec. The three series of measurements

[30] *Jour. Roy. Astron. Soc. Can.*, 12, 437-441, 1918.
[31] J. Storey, *Monthly Notices*, 92, 737-741, 1932.

may thus be assumed to be lessened by blended spectra by approximately 3 per cent.

Various series of measurements will be inspected on the justifiable assumption that deviations from the equatorial velocity of 2.02 km. per sec. are due to a combination of micrometer and blended spectrum errors.

Micrometer measurements of the rotational displacements of a selected group of spectrum lines, always measured in the same manner, will presumably be affected by the same systematic error, usually a few ten-thousandths of a millimeter, in the observations at all latitudes. If e be the systematic error, v' the measurement of the displacement, v the component of the rotational velocity V directed to the observer at an inclination γ to the direction of rotation at the observed point on the sun, and ϵ the component of the earth's velocity directed to the point observed, all expressed in km. per sec., then,

$$v = v' + \epsilon - e,$$

and the rotational velocity at the point on the sun is,

$$V = v \sec \gamma = (v' + \epsilon - e) \sec \gamma .$$

The earlier observers used the approximation,

$$V = v' \sec \gamma + \epsilon ,$$

which is too small by $(\sec\gamma\text{-}1)\epsilon$, omitting the possible error e. This quantity is not large for observations on the solar limb, but it is serious for observations within the limb, when also the systematic error enlarged to $e \sec\gamma$, is more serious particularly in observations at the highest latitudes.

If further, the measured value v' is reduced by blended spectra, it will have to be enlarged by a small factor[7,8] which is approximately the same for the range of values of v' at least up to latitude 75°. If this factor be k, not conceivably falling outside the range from 1.01 to 1.09, then approximately,

$$V = k(v' + \epsilon - e) \sec\gamma.$$

The problem in any given series of observations of the solar rotation is to find reasonable values of k and e which will satisfy the equation,

$$2{\cdot}02 \cos^{1.315}\phi = d(v' + \epsilon - e) \sec \gamma.$$

In the pioneer visual spectroscopic observations of the solar rotation by Dunér[32, 33] and by Halm[34, 18] two strips of spectra from diametrically opposite limb points were juxtaposed, in the former by reflecting prisms and in the latter by an ingenious use of a heliometer and a large right-angled prism. In these observations a pair of absorption spectrum lines due to terrestrial atmospheric oxygen, λ6302.209 and λ6302.975, were measured along with two solar iron absorption lines displaced by rotation, λ6301.718 and λ6302.709. It is difficult to imagine how systematic micrometer errors could be present in such measurements; yet the comparative measurements of Dunér and Bergstrand given in Table VII indicate a systematic difference of 0.05 km. per sec., equivalent to about 0.0004 mm. The measurements exhibit large accidental errors, but they are surprisingly consistent considering the discomfort of observing with the grating spectroscope mounted on the large equatorial telescope. Halm's equipment on a stable mounting was supplied with sunlight by a siderostat, thus permitting rapid and comfortable observing.

From the results in Table VII it may be derived that the mean velocity of rotation at all latitudes observed by Dunér and Bergstrand is 1.359 km. per sec., which exceeds the mean value 1.343 derived from the adopted formula by 0.016 km. per sec., equivalent to a little more than 0.0001 mm.; while Dunér's mean value exceeds it by 0.024 km. per sec. or a little less than 0.0002 mm. Assuming average values of γ, values of k and e were estimated for Dunér's values in 1899-1901 as a 2 per cent. effect of blended spectrum and a systematic micrometer error of 0.0003 mm. equivalent to 0.04 km. per sec. The computed values V' with these corrections are given in Table VII in comparison with the values V'' from the adopted formula. The differences average zero but individually some of them are rather large. In arriving at the value k the greatest consideration was given to the rotation value for the highest latitude. However, the estimates of the errors are probably not far from the truth.

The velocities of rotation observed by Halm[18] are quoted in Table

[32]N. C. Dunér, *Nova Acta Reg. Soc. Sci. Upsaliensis*, Ser. 3, 4, Fasc. 2, 1-79, 1891.

[33]N. C. Dunér, *Ibid.*, Ser. 4, 1, Fasc. 6, 1-64, 1907.

[34]J. Halm, *Trans. Roy. Soc. Edingurgh*, 41, Pt. 1, 89-104, 1904.

TABLE VII

Rotation Velocity V km/sec. at Latitude ϕ and No. of Observations by Dunér at Lund, 1887-1889, and at Upsala with Bergstrand, 1899-1901; and Values derived from Various Formulae.

Dunér									Means
Year	No.	ϕ =	0°.4	15°.0	30°.0	45°.0	60°.0	75°.0	37°.6
1887	33	V =	2.11	1.98	1.68	1.30	.79	.38	1.37
1888	47	V =	2.03	1.90	1.67	1.28	.78	.44	1.35
1889	23	V =	2.20	2.04	1.78	1.25	.82	.36	1.41
1887-89	104	V =	2.09	1.96	1.70	1.28	.79	.40	1.37
1899	35	V =	1.95	1.94	1.62	1.23	.80	.33	1.31
1900	23	V =	2.14	1.98	1.77	1.35	.89	.53	1.44
1901	18	V =	2.10	2.01	1.71	1.20	.73	.32	1.35
1899-01	76	V =	2.04	1.97	1.69	1.26	.81	.39	1.36
1887-01	180	V =	2.07	1.97	1.69	1.27	.80	.40	1.37
Bergstrand									Means
Year	No.	ϕ =	0°.3	15°.0	30°.0	45°.3	60°.0	74°.8	37°.6
1899-01	30	V =	2.08	1.89	1.63	1.13	.78	.35	1.31
1899-01	$D-B$ =		−.01	.07	.06	.15	.02	.05	.05
		$V'=1.019\ (V-0.04 \sec \gamma)$:							
1899-01		V' =	2.042	1.966	1.680	1.241	.782	.348	1.343
		$V''=2.02 \cos^{1.315}\phi$:							
		V'' =	2.020	1.930	1.672	1.281	.812	.342	1.343
		Diff.	.022	.036	.008	−.040	−.030	.006	.000

TABLE VIII

Rotation Velocity V km/sec. at Latitude ϕ observed by J. Halm, Edinburgh, 1901-1906; and Values derived from: $V'=1.036\ (V-0.09 \text{ sec. } \gamma)$; and $V''=2.02\ \cos^{1.315}\phi$.

ϕ	V	V'	V''	Diff.	ϕ	V	V'	V''	Diff.
°					°				
2.3	2.042	2.022	2.019	.003	42.2	1.395	1.350	1.361	−.011
6.6	2.032	2.012	2.002	.010	45.3	1.309	1.261	1.272	−.011
9.4	2.002	1.981	1.984	−.003	48.7	1.219	1.168	1.170	−.002
12.4	1.972	1.950	1.958	−.008	51.6	1.127	1.071	1.080	−.009
15.6	1.952	1.929	1.923	.006	54.3	1.064	1.006	.995	.011
18.4	1.907	1.882	1.885	−.003	57.4	.970	.909	.896	.013
21.4	1.856	1.830	1.839	−.009	60.6	.869	.803	.792	.011
24.5	1.788	1.759	1.784	−.025	63.3	.785	.716	.705	.011
27.6	1.755	1.725	1.723	.002	66.4	.689	.616	.606	.010
30.7	1.657	1.622	1.656	−.034	69.4	.627	.550	.511	.039
33.3	1.596	1.559	1.596	−.037	72.5	.543	.461	.416	.045
36.4	1.561	1.523	1.518	.005	75.4	.425	.337	.330	.007
39.4	1.456	1.414	1.439	−.025	79.0	.338	.231	.229	.002
Means:					40°.9	1.344	1.296	1.296	.000

VIII for the averages of all observations at each latitude from 1901-1906, and in Table VIIIa as the means at various latitudes for each year. The excesses of the observed values over those, V'' in both Tables, calculated from the adopted formula are seen to increase with increasing latitude, indicating a fairly large positive systematic micrometer error. This is also indicated by the small value of b, namely 0.172, which is 0.07 smaller than the mean value from various spectroscopic investigations as shown in Table II. In Table VIII are given calculated velocities, V', with values of k and e, 1.036 and 0.09 km. per sec. or 0.0005 mm., respectively. It is to be noted that the value of k actually corresponds to a supposed blended spectrum effect of only 2 per cent., the same as assumed for Dunér's observations, since by the use of the heliometer each solar image with its own overlapping diffused sky light is also overlapped by the diffused sky light of the other image adjacent to it on the spectroscope slit, thus introducing

TABLE VIIIa

Rotation Velocity V km sec. at Latitude ϕ observed by J. Halm, Edinburgh, 1901-1906; and Values derived by Various Formulae.

			1901					Means
ϕ =	4°.0	12°.9	24°.7	34°.9	45°.0	54°.5	65°.2	76°.0	39°.7
V =	2.06	1.99	1.72	1.46	1.25	.98	.62	.29	1.30
				1902					
ϕ =	5°.0	15°.1	24°.3	34°.6	44°.9	54°.6	63°.8	74°.9	39°.7
V =	1.97	1.87	1.70	1.47	1.21	.94	.67	.37	1.28
				1903					
ϕ =	5°.4	15°.2	24°.9	35°.1	45°.0	55°.4	65°.5	74°.6	40°.1
V =	2.02	1.95	1.82	1.59	1.35	1.06	.76	.47	1.38
				1904					
ϕ =	5°.1	15°.1	25°.5	35°.3	44.9°	54°.9	65°.2	77°.3	40°.4
V =	2.06	2.00	1.82	1.60	1.37	1.09	.78	.43	1.39
				1905					
ϕ =	4°.9	14°.6	23°.9	33°.5	44°.6	54°.5	65°.1	76°.3	39°.7
V =	2.04	1.97	1.82	1.61	1.36	1.09	.77	.44	1.39
				1906					
ϕ =	5°.2	15°.8	25°.7	35°.4	45°.1	55°.1	64°.9	76°.3	40°.4
V =	2.01	1.91	1.77	1.59	1.30	1.02	.73	.43	1.34
				1901-1906					
ϕ =	4°.9	14°.8	24°.8	34°.8	44°.9	54°.8	64°.0	75°.9	40°.0
V =	2.03	1.95	1.78	1.55	1.31	1.03	.72	.41	1.35
				1.057 x V of 1902:					
	2.08	1.98	1.80	1.55	1.28	.99	.71	.39	1.35
Diff.	−.05	−.03	−.02	.00	.03	.04	.01	.02	.00
				$V''=2.02\cos^{1.315}\phi$:					
V'' =	2.01	1.93	1.78	1.56	1.28	.98	.70	.32	1.32
Diff.	.02	.02	.00	−.01	.03	.05	.02	.09	.03

a blended spectrum of double intensity. The differences, V'-V''' given in the Table average 0.000 and are reasonably within the bounds of accidental error. The estimate of the intensity of sky spectrum is in harmony with the equatorial value 1.97 km. per sec. derived at Edinburgh by Storey,[31] which on the assumption of a zero systematic error of measurement would seem to indicate an effect of 2.5 per cent. from blended spectra. On the assumption that the low values obtained by Halm in 1902 are due to a greater effect of blended spectra than for the means for 1901-1906, the 1902 values are increased by the factor 1.057. The differences between these values and the means of all years given in Table VIIIa appear to have a systematic tendency, as though blended spectra do not account for the differences completely.

It should be recalled that Halm noticed the lessening error due to hazy skies and discontinued his observing whenever the strip between the two limb spectra "became so bright as to show traces of the absorption lines of the solar spectrum", and he assumed therefore "that the spectrum of the diffused daylight cannot have seriously influenced the measured displacements". His assumption in this regard, like that of the Ottawa observers at the beginning of their investigations, appears to have been slightly too hopeful as indicated by the above calculations and the subsequently observed lower value at Edinburgh.

In later spectroscopic investigations of the solar rotation the visual methods were supplanted by photographic recording of the limb spectra, with the great advantage that if error of measurement be suspected in any series of observations the plates may be remeasured. It is suggested that when results differ markedly from those derived from the adopted formula some measurements should be repeated to test for the presence of the treacherous micrometer-oil error; and also to determine the influence of blended spectra in the series by measuring selected groups of spectrum lines unequally affected by the blends of spectra foreign to the limb spectra.

It is of interest to compare the extensive results, V km. per sec. at latitude ϕ of the Mt. Wilson observations[27] made in 1906-7 and 1908, with values V''' km. per sec. calculated from the adopted formula, $2.02 \cos^{1.315}$:

1906-7 and 1908

ϕ =	0°.3	7°.6	15°.0	20°.9	29°.8	35°.9	44°.7	51°.2	59°.9
V =	2.068	2.019	1.950	1.839	1.672	1.509	1.285	1.099	.836
V'' =	2.020	1.997	1.930	1.847	1.676	1.531	1.289	1.093	.815
Diff.	.048	.022	.020	−.008	−.004	−.022	−.004	.006	.021

1908

ϕ =	0°.4	4°.1	11°.2	14°.9	19°.2
V =	2.062	2.040	1.991	1.944	1.867
V'' =	2.020	2.013	1.970	1.929	1.874
Diff.	.042	.027	.021	0.15	−.007

ϕ =	29°.8	34°.1	44°.8	49°.6	60°.1
V =	1.669	1.557	1.287	1.137	.806
V'' =	1.676	1.576	1.287	1.142	.809
Diff.	−.007	−.019	.000	−.005	−.003

Apart from the high residuals at and near the equator the differences are fairly low up to 60° of latitude beyond which the comparison was not made since the assigned radially projected latitudes at the limb are too much larger than the actual latitudes of the points of observation within the limb. The mean values for all latitudes are:

1906-7 and 1908, $\phi = 29°.5$, $V = 1.586$, $V'' = 1.578$, Diff. $= 0.008$
1908, $\phi = 26°.8$, $V = 1.636$, $V'' = 1.630$, Diff. $= 0.006$

The mean differences are surprisingly small and are accounted for in the residuals of the equatorial zone.

The average value of the equatorial velocity of the solar rotation from the individual determinations of Dunér, Bergstrand (Upsala), Halm, Storey and Wilson, Storey (Edinburgh), Adams, St. John (Mt. Wilson), Hubrecht (Cambridge), Schlesinger (Allegheny), Evershed and Royds (Kodaikanal), J. S. Plaskett, De Lury, H. H. Plaskett, O'Connor (Ottawa), is very closely 2.00 km. per sec., or 14°.23 per day. This is 1 per cent. lower than the adopted value. If 1.025 be regarded as a fair estimate of the factor k for blended spectra, then the value of e necessary to reproduce the adopted values from the means is 0.029 $\sec\gamma$ km. per sec., or 0°,21 $\sec\gamma$ for angular velocity at latitude ϕ. In other words, it would appear that the average spectroscopic determination of the solar rotation is affected by a

2.5 per cent. effect of blended spectra and a 1.5 per cent. positive error of measurement, for the equatorial value, or equivalent to about 0.0007 mm. for the dispersions commonly employed.

As previously indicated, differences in measured velocities from lines of various intensities result from blended spectra, and also from the micrometer-oil error which depends on the duration of the measurement which varies with the character of the spectrum lines. If a positive error be present, strong lines like λ4227 and Hα requiring a longer time to measure would yield larger values than the more rapidly measurable weaker spectrum lines. In some Ottawa measurements the rotational displacements of λ4227 were measured larger or smaller than those of adjacent lines depending on the order of measurement of the lines in the spectra from the two limbs, since the oil causes a motion or settling in one direction of the micrometer nut and with it the plate being measured. While measurements of these strong lines[27] may have been thus affected in observations consisting of two strips of spectra, it is improbable that any such error can account for the very large velocities, about 2.5 km. per sec., from the H and K lines of calcium in prominences such as measured by Evershed.[35] The vapours producing these lines and to some extent Hα may be regarded as having come by outbursts free from the general solar surface and retaining their larger linear velocities of rotation associated with nearness to the very rapidly rotating dense nucleus of the sun. This process may also explain the larger velocities of incipient sunspots and groups with their accompanying faculae, the latter retaining their greater linear velocities longer than the sunspots which are more intimately attached to the general solar surface. Larger velocities found above the general solar surface are thus regarded not as due to level per se, but rather as due to freer space where incipient large velocities may be retained with less obstruction from the general solar surface.

Details of the measurements of the Ottawa observations from which the new formula for the law of the solar rotation was derived, are as follows: The micrometer-oil error e was deduced from the "violet left" measurements of 12 spectrum lines, λ5544.157 to λ5638.488, in the two series of 1911 and 1912 observations on 19 and

[35] J. Evershed, *Monthly Notices*, 95, 503-509, 1935.

25 plates, mainly from a consideration of the oil-error curve[6] and the average duration of the measurement of a spectrum line in each of the 3 strips of limb spectra, though consideration was also given to the average difference, d'-d'', between the displacements measured "violet left" and "violet right" for 19 spectrum lines on 112 observations previously measured. The average value of e deduced for the 12-line measurements was 0.0006 mm. which corresponds to a difference in rotational velocity at latitude ϕ, of 0.011 secγ. If 0.014 had been adopted instead of 0.011, the minute polar displacements would have been reduced to 0.000 instead of 0.003 km. per sec., and the other residuals improved in the mean. In regard to the estimate of the factor k to correct for the effect of blended spectra present, it appears from the measurements, previously mentioned, of 56 observations of the equatorial velocity simultaneously observed[13] at the limb and midway positions that the equatorial velocity is one per cent. or more greater than the midway value of 1.99 km. per sec., while about 2.03 km. per sec. is approximately indicated as the "asymptotic" velocity from some measurements of weak and strong lines unequally affected by blended spectra, and therefore a velocity of 2.020 km. per sec. is probably very close to the equatorial velocity, or in other words, for the observations in question, the factor k has the value 1.033. As a further indication that this value is probably correct, it is the value derived from sunspots; and the Greenwich measurements of sunspots are reproduced by the same exponent of the cosine in the new formula as is found for the Ottawa observations. The observed velocities and their means corrected for the above errors, and values derived from the adopted formula, are given below.

1911, 19 observations corrected for e as 0.010 secγ

ϕ =	0°.3	14°.6	29°.1	43°.3	57°.2	69°.7	74°.0	76°.5	Polar
V =	1.947	1.883	1.641	1.278	0.868	0.493	.0359	0.288	0.006

1912, 25 observations corrected for e as 0.012 secγ

ϕ =	0°.3	14°.6	29°.2	43°.6	57°.6	70°.3	73°.7	76°.2	Polar
V =	1.960	1.864	1.642	1.276	0.861	0.476	0.376	0.341	0.000

1911-1912, 44 observations corrected for e as 0.011 secγ

ϕ =	0°.3	14°.6	29°.2	43°.5	57°.4	70°.0	73°.9	76°.4	Polar
V =	1.955	1.874	1.642	1.277	0.864	0.483	0.369	0.318	0.003

Mean values of V multiplied by 1.033:

V' =	2.020	1.936	1.696	1.319	0.893	0.499	0.381	0.328	0.003
				$\cos^{1.315}\phi$:					
	.9999	.9578	.8375	.6564	.4434	.2440	.1856	.1496	.0000
				2.020 $\cos^{1.315}\phi$:					
V'' =	2.020	1.935	1.692	1.326	0.896	0.493	0.375	0.302	.000
$V'-$									
V'' =	.000	.001	.004	−.007	−.003	.006	.006	.026	.003

The residuals are very small. In regard to the largest residual 0.026, it would appear that this is due to the 1912 observations, as the value 0.288 km. per sec. for V at 76°.5, when multiplied by the factor 1.033 becomes 0.298 which yields the residual −0.004 in comparison with the adopted value of the formula.

Denoting the new formula for the law of the solar rotation by F thus,

$F = 14°.37 \cos^{.315}\phi$ per day $= 2.020 \cos^{1.315}\phi$ km. per sec., results of various determinations of the solar rotation may be expressed in conclusion as follows:

F = Rotation of Sunspots (esp. Greenwich, 1878-1933);
$= 0.988 \cos^{-.63}\phi$ (Rotation of Faculae and Flocculi);
$= 1.033$ (Spectroscopic Values, Ottawa, 1911-1912);
$= 1.025\ (V - 0.029 \sec\gamma)$ km. per sec. for the average V by all spectroscopic measurements.

From the Greenwich observations of recurrent sunspots and the Ottawa spectroscopic measurements corrected for blended spectrum effects and systematic micrometer error, it must be concluded that sunspots and the general solar surface rotate identically; while faculae and flocculi move about one per cent. more rapidly, and prominences still more speedily, as though retaining some of their larger linear velocity brought from beneath the solar surface when their vapours were exploded forth.

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THE CLOCK CONTROLLED GRAVITY DRIVE FOR SMALL TELESCOPES

By H. Boyd Brydon

TWO drives for small telescopes were described recently in this Journal.[1] One of them was actuated by a falling weight, its rate of fall being controlled by a clock. This form of drive appears to be due to F. J. Sellars, M. I. Mech. E, who used it successfully for a 3-in. refractor.[2]

While the simplicity and low cost of this drive render it peculiarly suited to the amateur's telescope of moderate aperture, in its original form the clock was exposed to rather large and uncertain variations in the work it had to do as it acted directly upon the suspension of the driving weight. In the design referred to above this objection is removed; the clock control is applied by a worm gear acting through a train of spur gears which effect the requisite speed reduction.

A new form of this drive has now been developed in which by the use of a second worm the speed-reducing gear train is not needed. In the new form the drive is more compact and lends itself also to great variety of arrangement. One type is shown in Fig. 1 which may be compared with Figs. 2 and 3 in the article noted.

Certain other changes have been made. Among these the manner of reeving the operating cord is altered to give the slow motion device control in both directions when setting the telescope in right ascension. It is shown in diagram in Fig. 1a. In the following detailed description, for convenience the telescope is assumed to be east of the pier and about an hour east of the meridian. In Fig. 1 one end of the cord is secured at *A* to the drum *B* and five turns taken round it. The cord is then passed twice round the main wheel *C*, secured to the polar axis, then the cord passes down to and again five times round the drum, thence round the pulley *D* which carries the driving weight

[1] "Two inexpensive drives for small telescopes." This Journal, vol. 33, p. 5, 1939.

[2] "A simple, inexpensive and effective clock drive for small telescopes." *Jour. B. A. A.*, vol. 40, p. 222, 1930.

W and, with the pulley *D* hoisted to the top of its travel, is made fast to the base of the drive at *E*.

A minor change is the use of a flexible metal cord such as braided brass picture wire instead of the "heavy linen traverse cord" previously specified.

Still referring to Fig. 1, in operation, the drum which revolves

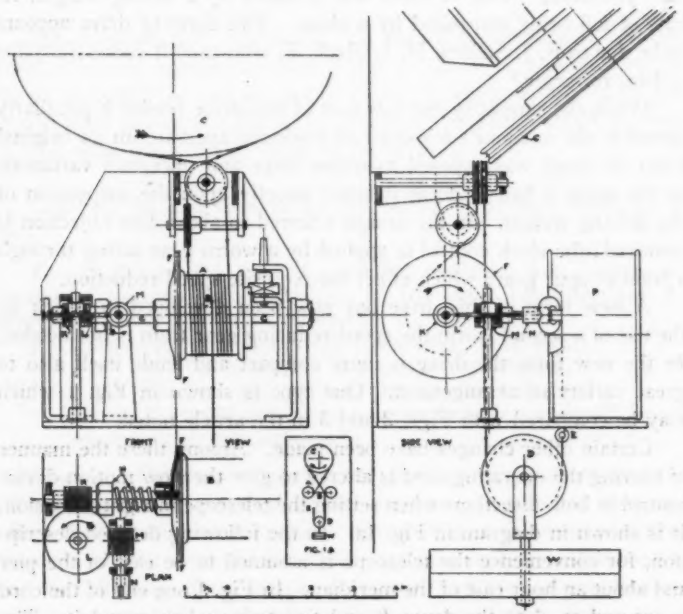

FIG. 1.—The New Form of Clock Controlled Gravity Drive.

on the drum shaft *G* as its bearing can cause that shaft to turn with it by means of the friction plates *F*. *K* is a worm secured to the shaft *G*. It replaces the pinion *P* shown at this point in the earlier design and is in gear with the worm wheel *L*.

Now, given adequate friction between the friction plates (which is regulated by the nut and compression spring *H*, see the plan), the rotation of the drum will cause the worm *K* to rotate the wheel *L* at

a speed depending only on the rate of fall of the drive weight W, which in turn depends only upon the friction in the drive and mounting. But the wheel is prevented from turning thus freely by being also in gear with a second worm M. Being connected (by a jaw clutch N for convenience) to the winding spindle of a "dollar alarm" clock P, the rotation of the worm M and consequently the rotation of the wheel L and of the drum and the polar axis are controlled by the (constant) speed of the winding spindle of the clock.

As the winding spindle in these clocks commonly rotates (clockwise as seen from the back of the clock) once in six hours, it is only necessary to make the effective diameter of the drum B one-fourth that of the main wheel and regulate the clock to sidereal time for the polar axis to be rotated at the proper speed.

In this as in the earlier design, all the work of driving the telescope is done by the weight W. The whole mechanism in fact acts as slave under the control of the master P whose function is simply to rotate the worm M thereby permitting the shaft G to be rotated by the weight W.

The adaptability of this drive is well illustrated by comparison of Figs. 1 and 2.[3] In both the clock is easily seen when setting the telescope in right ascension but Fig. 2, besides being more compact has the advantage that the R.A. slow motion has a finer adjustment and can be fitted on either or both sides of the pier. In Fig. 2 also the mechanism is arranged for enclosure in a glass or sheet metal case for protection.

It is of course desirable that the worm wheel L be properly cut and ground to fit the worms with which it is in gear, but if the telescope be not too heavy an effective drive can be built with "Meccano" parts. The supports for the several shafts can be bent up from ⅛-in. strap iron of suitable width. The plates forming the case in Fig. 2 can be joined together by small angles, or better by corner posts as shown. The mechanism should be mounted on a metal or hardwood base plate screwed or bolted to the pier.

When an existing hand drive such as the clamp and tangent screw

[3]Construction drawings of both of these arrangements can be obtained.

[4]"A. H. Young's Simple Mounting for the Six-inch Reflector." This JOURNAL, vol. 33, p. 185, 1939.

motion used in the Young mounting[4] is to be replaced by a drive of this type, the main wheel is most conveniently secured to the lower end of the polar axis, but if the weight there is not enough for the required travel of the driving weight the wheel can replace the right ascension clamp which is no longer needed.

As the successful performance of any mechanism depends upon

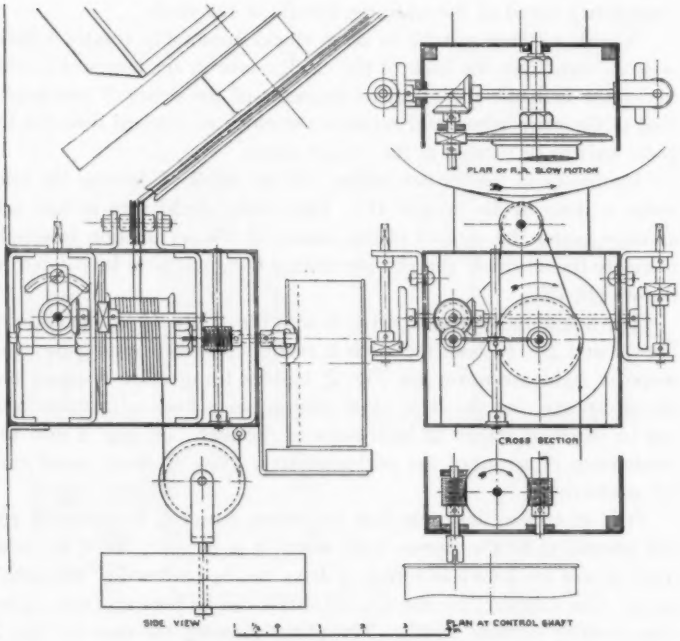

FIG. 2.—Adaptation of Drive of Fig. 1.

the mutual adjustment of its several parts, the following suggestions are offered for consideration when putting a new drive into service:

1. See that the polar axis turns smoothly and freely in its bearings. If necessary, grind in the cone bearing with fine emery. Clean thoroughly and lubricate with a mixture composed of three or four

volumes of medicinal paraffin (liquid petrolatum) to one part of white vaseline.[5]

2. Secure the telescope in correct position in its saddle and balance carefully about the polar axis with the counterbalance weights.

3. Reeve the operating cord as described.

4. With no pressure between the friction plates determine with shot the least weight W needed to move the telescope steadily in right ascension on each side of the pier. If the weights differ correct the balance of the telescope about the polar axis.

5. Set up the friction plates just enough to prevent the weight so found from rotating the polar axis.

6. Again on each side of the pier, gently move the telescope back and forth in right ascension by the slow motion device, adjusting the friction plates so that they do not slip.

7. Place the telescope east of the pier, clamp in declination and start the control clock. The weight should now drive the telescope steadily and continuously and without the friction plates slipping.

8. Add or remove weight and adjust the friction plates until all of the above conditions are met with the least weight and least pressure between the friction plates which will give steady operation.

9. As the performance of the drive will improve with use, run it for several hours daily when first put into service.

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[5]This lubricant was recommended in *English Mechanics*, vol. 7, p. 534, 1939, in a note entitled "An excellent clock oil." I have found it very satisfactory; it does not creep nor gum. Mix warm. Use less vaseline in cold climates.

COMMUNICATIONS
FROM THE
DAVID DUNLAP OBSERVATORY
Number 4

FIVE NEWLY DISCOVERED Be STARS

By JOHN F. HEARD

IN THE course of the radial velocity programme recently completed at this observatory[1] five stars not listed in Merrill's and Burwell's catalogue of Be stars showed evidence of having hydrogen emission lines in their spectra. Spectrograms of these stars taken on Astra VIII plates have been obtained to record Hα and so confirm the existence of emission. Three of the spectra have been studied under higher dispersion (25-inch camera) because the emission components seemed to have structure.

H.D. 9709: R.A. (1900) $01^h\ 30^m.0$, dec. $+46°\ 36'$,
vis. mag. 7.02, type (H.D.) B9, (D.D.O.) B8ne.

Hβ has rather weak double emission centrally superposed on very broad absorption; similar structure is suggested, but not clearly seen, at Hγ and Hδ. The emission components at Hβ are of about equal intensity with a separation of about 3.7 A. An Astra VIII plate shows moderately strong emission at Hα.

No changes in the spectrum are indicated on 14 plates between J.D. 2428102 and 2429184.

H.D. 26398: R.A. (1900) $04^h\ 05^m.1$, dec. $+16°\ 22'$,
vis. mag. 7.02, type (H.D.) B8, (D.D.O.) B6e.

Hβ, Hγ, and Hδ show narrow central emission (fairly strong at Hβ, weak at Hγ and uncertain at Hδ) within absorption lines of moderate width. On one 25-inch camera plate the Hγ emission gives the appearance of being double with components of about equal intensity and separation of about 1.8 A. An Astra VIII plate shows very strong emission at Hα.

Seven plates from J.D. 2428073 to 2429299 fail to indicate any changes in the spectrum.

[1]Pub. D.D.O., vol. 1, no. 3, 1939.

H.D. 142926: R.A. (1900) $15^h\ 52^m.2$, dec. $+42°\ 51'$, vis. mag. 5.61, type (H.D.) B8, (D.D.O.) B9e.

Indistinct double emission is suggested by the structure of $H\beta$, $H\gamma$, and $H\delta$ which have sharp absorption cores flanked by broad, faint absorption wings. Astra VIII plates show moderately strong emission at $H\alpha$.

About 30 plates between J.D. 2428206 and 2429455 fail to indicate any changes in the character of the spectrum.

H.D. 179218: R.A. (1900) $19^h\ 06^m.6$, dec. $+15°\ 37'$, vis. mag. 7.15, type (H.D.) B9, (D.D.O.) B9e.

$H\beta$ has weak, narrow emission—doubtful on some plates—on moderately wide absorption. An Astra VIII plate (of J.D. 2429582) shows moderately strong emission at $H\alpha$.

Seven plates between J.D. 2428397 and 2429582 indicate possible variation of the intensity of the $H\beta$ emission, though the emission there is so weak as to make the conclusion uncertain.

H.D. 189689: R.A. (1900) $19^h\ 56^m.2$, dec. $+32°\ 31'$, vis. mag. 7.21, type (H.D.) B9, (D.D.O.) B8e.

There is weak, narrow, central emission at $H\beta$ and a suggestion of the same at $H\gamma$. An Astra VIII plate shows $H\alpha$ moderately strong in emission.

No change in the spectrum is indicated by five plates between J.D. 2428057 and 2429226.

Some interest attaches to the possibility of these stars having developed emission lines since they were first observed spectroscopically. The evidence available, however, is not very conclusive. It appears that only H.D. 179218 is within the regions covered by the discovery surveys of Merrill and others.[2] Moreover, with the exception of H.D. 142926, there is no record of previous slit spectrograms; and, except possibly for H.D. 26398, the emission lines in the photographic region are so faint as probably to escape notice on slitless spectrograms. For H.D. 26398 the difference in classification, B8 (H.D.) and B6e (D.D.O.) may represent a change in the spectrum.

[2]Ap. J. vol. 61, p. 389, 1925; vol. 76, p. 156, 1932.

With regard to H.D. 142926, Plaskett[3] remarks that the hydrogen lines are "broad and diffuse" on the Victoria plates of 1919 and 1920. On our plates of 1936-39 the hydrogen lines arrest attention with their unusually sharp cores. From this it seems probable that H.D. 142926 has developed its emission characteristics since 1920.

With regard to H.D. 179218, the fact that the now fairly strong emission at Hα is not recorded in the survey by Merrill and others would indicate that the emission has probably appeared since 1925.

David Dunlap Observatory,
November 1939.

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[3]Pub. D. A. O. vol. 1, p. 287.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

The Dresden Meteorite

The Dresden Meteorite, which fell in Western Ontario on July 11, 1939 (approximate weight 88 lbs), has been purchased privately by the directors of the London Life Insurance Co. and presented to the University of Western Ontario, London. In these troubled times it is gratifying indeed to find a group of business men taking such a step in the interests of science. Not only has the detailed scientific study of the stone been greatly facilitated by this generous gift, but the meteorite will be safely housed in an institution of learning where it is certain to serve as a centre of interest in meteorites and meteors, and where, throughout the years, it will help to familiarize the public with the general appearance and nature of these interesting objects.

Through the kind cooperation of Prof. Kingston, head of the department of mathematics and astronomy at the University of Western Ontario, the Dunlap Observatory has secured an excellent tinted cast of the Dresden meteorite and it is planned to have this on display at the Observatory along with a 13-oz. fragment from the original stone.

Bright Meteors, Observed Near Bologna July-August, 1939

Once again our Italian member, M. Eppe Loreta, has contributed a fine set of Perseid observations, made both by himself, in Bologna, and by members of a group of interested amateurs located at various neighbouring stations. In the present note the heights and train observations of eight bright meteors observed by this group will be discussed. The observers cooperating in the programme are listed below:—

Name	*Place*	
M. Eppe Loreta	Bologna	(φ 44°.5 N, λ 0^h 45^m.5 E).
Mme. C. Corucci	Livorno	(43 .5 0 41 .3).
M. R. Walter	Schio	(45 .7 0 45 .4).
M. G. Peisino	Parenzo	(45 .2 0 54 .4).
M. H. Hirschler	Tigring	(46 .6 0 56 .7).
M. G. Zaffi	Codigoro	(44 .8 0 48 .5).

Mme. Corucci and M. Walter have cooperated regularly with Loreta for some time now. The visual observations for all members of the above group were sent by M. Loreta to the Dunlap Observatory and computations for height have been carried out by the writer, using a graphical adaptation of the Newton-Denning method.

I July 15, 1939, at 21^h 07^m G.C.T. This meteor was observed at Livorno (mag. −2, very slow, white), Parenzo (mag. −5, duration 4 or 5 sec., yellow-red), and Tigring (mag. −5, blue). No train was reported.

Height of appearance	112 km
" " disappearance	45
Path length	84

Approximate radiant α 20^h 10^m, δ +27°.

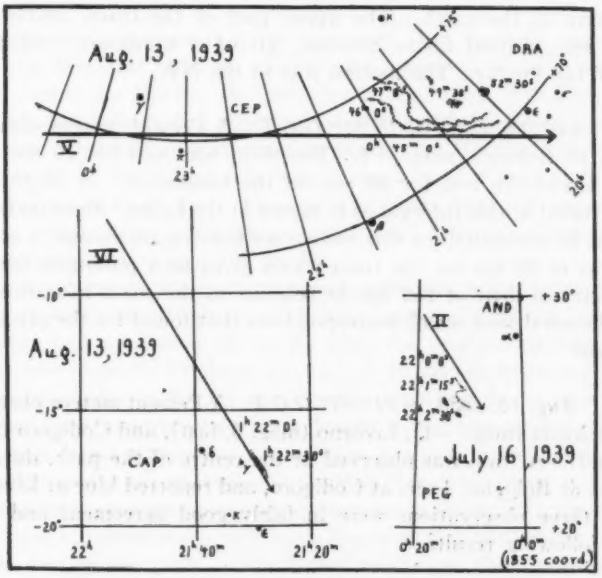
The above values are not very accurate as the three observations were in poor agreement. There is no doubt, however, that this fireball was typical of the slow, bright meteors which penetrate to points well below the ionized layer.

II July 16, 1939, at 22^h 00^m G.C.T. A Perseid observed at Bologna and Schio, magnitude estimates −1 and −2 respectively. Only a mean height, 102 km, could be computed for the path from the two observations. Assuming the Perseid radiant, however, the following values were found for the trail as observed at Bologna.

Height of appearance	112 km
" " train	95
" " disappearance	92
Path length	48

The persistent train of this meteor was observed by Loreta in binoculars of 1.8 inch aperature for a period of 150 sec. His drawing of the drift and interesting changes of shape is reproduced in the figure. The drift was down, that is to the E, and assuming motion across the line of sight we get a minimum possible velocity of drift of 90 km/hr relative to the earth.

III July 17, 1939, at 21h 25m G.C.T. Possibly a Perseid, observed at Bologna and Schio, magnitude estimates 0 and −2 respectively. Only a mean height could be computed, 90 km. The radiant was indeterminant in the solution but if this was a Perseid the radiant was at an altitude of about 20°. Loreta observed a train of 3 sec. duration at the end of the path.



The Persistent Trains of Three Bright Meteors Observed by M. Eppe Loreta in Bologna.

IV Aug. 12, 1939, at 21h 14m G.C.T. Observed at Bologna and Livorno, magnitude estimates −1 (slow) and −4 (slow) respectively. Observations in good agreement.

Height of appearance	78 km
" " disappearance	50
Length of path	40

Radiant at α 16h 00m, δ +24°.

V Aug. 13, 1939, at 0h 45m G.C.T. Observed only at Bologna, a Perseid of magnitude −3. The train was visible to the naked eye for 60 sec. and in the binoculars for 450 sec. Its changes in position and form have been reproduced in the figure. No height could be computed for this meteor but if we assume the train to be at the normal height of 90 km then minimum possible velocity of drift for the part of the train which endured the longest is 67 km/hr relative to the earth. The upper part of the train, visible only 120 sec., drifted faster however, giving a minimum velocity of drift 148 km/hr. The motion was to the NW.

VI Aug. 13, 1939, at 1h 22m G.C.T. A Perseid meteor observed only at Bologna, mag. +1. The train was seen for 10 sec. with the naked eye and for 30 sec. in the binoculars. A slight drift was noted in this interval as is shown in the figure. Since no height could be computed for this meteor we must again assume a normal height of 90 km for the train which gives us a minimum possible velocity of drift of 150 km/hr relative to the earth in a direction to the northwest which corresponds to that found for the preceding meteor.

VII Aug. 13, 1939, at 21h 05m G.C.T. A Perseid meteor observed at Bologna (mag. −1), Livorno (mag. 0, fast), and Codigoro (mag. 0, fast). A train was observed at the centre of the path, duration 3 sec. at Bologna, 4 sec. at Codigoro, and reported blue at Livorno. The three observations were in fairly good agreement and gave the following results.

Height of appearance	126 km
" " train	108
" " disappearance	92
Length of path	105

Perseid radiant (assumed) at altitude 19°.

VIII Aug. 16, 1939, at 21h 22m G.C.T. A bright sporadic meteor observed at Bologna and Livorno, magnitude estimates −2 at each station, reported very fast. Observations were in good agreement for end point, rather uncertain for the beginning point. Two explosions occurred near the end of the path and at this point a

hazy train was visible for 2 sec. Solution for height gave the following.

Height of appearance	142 km
" " train	65
" " disappearance	60
Length of path	84

Approximate radiant at α 21^h 15^m, δ $+40°$.

In summary we see that the two very slow sporadic meteors were the brightest, had no trains, and appeared at an average height just under 100 km, disappearing under 50 km. The Perseids with heights determined appeared at about 120 km, disappeared at 90 km. One fast sporadic meteor penetrated the atmosphere to a height of 60 km. The only height measure of a long enduring train placed it at 95 km. The trains of short duration appeared over a wide range. Minimum velocity of drift for three long enduring trains averaged 130 km/hr.

Loreta notes in his correspondence with the writer that most of the Perseids magnitude 1 and fainter have the brightest part of the train half way along the path, while the brighter members of the shower have the brightest part of the persistent train near the end of the visible path. He suggests that this may be because the brighter ones penetrate to a lower height in the atmosphere. This may be a factor, though in my opinion it seems more likely that the original size of the meteoric particle has more to do with it, as terminal bursts seem more likely to occur in the brighter meteors and these terminal bursts will leave the brightest part of the train at the end of the path. It is hoped to discuss this question at greater length in a future number of the JOURNAL as some of the photographic results obtained this last summer at the Dunlap Observatory should throw some light on it.

In conclusion I would again like to express my admiration for the way M. Loreta continues to carry on with his very efficient and productive programmes of observation. He is a fine example for amateur astronomers the world over, and we very much appreciate his cooperation.

P. M. M.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Notes from the Dominion Astrophysical Observatory

Continuing the observing statistics last given we have the following record for the months.

Month	1939		20-year average	
	Nights	Hours	Nights	Hours
April	13	68.5	17	99.5
May	16	86	21	106.9
June	11	39.8	20	93
July	20	112.4	24	126
August	24	136.8	24	149
September	21	141	20	150.5

As usual this summer a number of astronomers and scientists visited the institution. Dr. Jessica Young Stephens of Washington University, St. Louis, Kansas, who is known for her computations on the orbits of asteroids and comets spent a day at the observatory. She was accompanied by Professor Stephens.

Dr. and Mrs. A. B. Wyse of the Lick Observatory spent a week-end at the observatory, discussing with the staff problems connected with the nebulae in which Dr. Wyse is interested.

Dr. T. S. Jacobsen, professor of astronomy at the University of Washington, Seattle, spent two days measuring plates of Cepheid variables taken by himself here two years ago.

Professor F. C. Jenkins of the Department of Physics, University of California, spent a week at the observatory. He is a joint author with Dr. McKellar of our own staff of a paper on an extensive study of the band spectrum of lithium.

Mr. Glen C. Madill, magnetician at the Dominion Observatory, Ottawa, who had been making a magnetic survey of the West Coast, paid a brief visit to the observatory.

Mr. R. Meldrum Stewart, Dominion Astronomer and Director of the Ottawa Observatory, spent a week at the observatory in August, discussing matters of administration and designing equipment in connection with the seismograph.

Professor F. C. Leonard of the University of California at Los Angeles, who was exchange professor at the University of British Columbia this summer, spent a few days here on his way home, and lecteured on "Meteorites" before the local astronomical society.

Professor S. L. Boothroyd of Cornell University and Mrs. Boothroyd were visiting on the Coast in early October. Professor Boothroyd spent a day at the observatory renewing acquaintances and discussing problems of common interest. He plans to use part of his sabbatical year of leave in photographing the spectra of meteors, for which he is securing new and powerful equipment.

The seismograph vault mentioned in previous "Notes" was satisfactorily completed at the end of March and during the summer Dr. E. A. Hodgson, the Dominion Seismologist, spent a month here installing the instruments. Some of these were from the former station at Gonzales, about ten miles distant, where the work has now been discontinued. Later, it is hoped to secure some new instruments as the Department wishes to make this station one of the best. Mr. K. O. Wright is looking after the instruments.

Considerable work has been done during the late summer by the Public Works Department in painting the two houses on the Hill, as well as the office building. The interior of the latter has been completely redecorated and is in consequence, very pleasing in appearance.

The ground floor of the dome building has been remodelled also. For some time there has been a desire on the part of the staff to have a little machine-shop equipment, by means of which small jobs could be undertaken by themselves. A lathe and drill press and some other small pieces of equipment have now been ordered and a special room prepared as a machine-shop. At the same time, a long-felt want has been met in the provision of wash rooms to serve the needs of our numerous visitors.

Minor improvements to the 72-inch telescope have been made. The iris covering the mirror, formerly opened and closed by hand, can now be operated by motor. Likewise, the raising or lowering of the cassegrain mirror is carried out by electric motor. These improvements lessen the manual labour formerly necessary.

Some improvements based upon experience in its use are being

made in the optical system of the microphotometer, while a second projection machine for measuring spectra has been completed.

Dr. J. A. Pearce was the official representative of the observatory at the opening of the Texas Observatory, where many prominent men of science were gathered.

Dr. C. S. Beals attended the Astrophysical Congress held in Paris in July as a guest of the Singer-Polignac Foundation where he presented an important paper on "P Cygni and Wolf Rayet Stars". He took occasion also to visit Amsterdam, Utrecht and Leiden to discuss with the scientists there problems of mutual interest. Both he and Mrs. Beals, who accompanied him, were glad to get away from Europe just before war was declared.

Dr. R. M. Petrie was the representative of the observatory at the A.A.A.S. meeting at Palo Alto, while Dr. Andrew McKellar served likewise for the Berkeley meeting of the A.A.S. Both presented different sets of papers prepared by members of the observatory staff.

Your scribe was unfortunate to suffer a relapse from last year's illness and spent a few months in hospital this summer. It was an experience he is not anxious to have repeated. While not yet fully restored to normal health, he is able to do a little work, for which he is very grateful. W. E. H.

Rediscovery of Comet Faye

Dr. H. M. Jeffers, of the Lick Observatory, has rediscovered Comet Faye as follows:

1939 November 3.1674	Magnitude 16
R.A. $20^h\ 13^m\ 28^s.3$	Description—Nucleus, but no
Dec. $-10°\ 18'\ 15''$	tail reported

This comet was originally discovered by Faye in 1843. It was rediscovered on 10 of its returns, in 1851, 1858, 1866, 1873, 1881, 1888, 1896, 1910, 1925 and 1932. It was not discovered at two returns, in 1903 and 1918. The elements at its last return, 1932 IX, were as follows:

T 1932 Dec. 5.7	q 1.617 A.U.
ω 199°.862	e 0.5711
Ω 206 .225	mag. 10
i 10 .602	

The predicted time of the next perihelion passage was April, 1940. This comet is one of Jupiter's family.

Comet Friend, 1939

Mr. Clarence L. Friend, an amateur astronomer of Escondido, California, discovered a faint new comet in Hercules ($16^h\,31^m$, $+35°$) on November 1. The object is diffuse; no tail was detected.

Its position, as determined from observations by L. Cunningham at Harvard Observatory, is as follows:

1939 November 4.98	Magnitude 12
R.A. $16^h\,52^m.9$	Daily motion: $7^m.5$ east; 10′ south.
Dec. $+34°\,03'$	

The comet has since been observed at a number of stations here and in Europe.

An Appeal for Fundamental Research

In connection with the dedication of the new Technological Institute of Northwestern University, former President Herbert Hoover, speaking as an engineer, appealed for greater emphasis on research in pure science. After dealing with the contributions pure science has made to technological progress, he quoted figures as to the expense of research in pure science. These figures apply, of course, to the United States.

> Our pure Science research is dependent largely upon our universities. Including that portion of men and money which they can set aside, plus that from all other agencies, it certainly does not amount to $20,000,000 a year. We allow pure science an expense account of about five per cent. of what we allow for cosmetics. Pure science research is therefore the poor relation, but he furnishes the family wisdom.

Rubber in the 200-inch Telescope

The Goodrich Rubber Company has recently pointed out that in the construction of the 200-inch telescope there have already been eight new rubber problems to solve: an air-cell cushion to hold the glass during grinding, a way of attaching the cushion to the metal base, seals to protect the machinery from the grinding compound, hose for draining the grinding sludge, a belt for handling, seals close the honeycomb back of the mirror, rubber cushion for the wheels of the dome mounting, and weather seals for the dome shutters.

F. S. H.

WHAT OF THE FUTURE?

Some amusement was provided by the appearance in American papers of a despatch from London dated October 27 which stated that the *British Journal of Astrology* had suspended publication because of the "uncertainty of the immediate future." The natural thought was that the astrologer, who claims that by reading the sky he can forecast one's future, should make special efforts to enlighten the people during these serious times!

It is remarkable that such superstition still persits. The Copernican theory of the universe is universally accepted. The earth is simply one of a group of planets revolving about the sun, and the fixed stars, other suns, are millions of millions of miles away. How can the positions of these bodies at the time a person is born determine what will happen to him all through his life? Still further, Newton demonstrated that these bodies move in accordance with the principle of universal gravitation and he supplied the method by which the astronomer is able to compute the precise direction and distance and the force of attraction of each planet at any moment in the past or the future. The sun and the planets and their satellites comprise a system operating according to definite mechanical laws. Ours is an orderly system. It is simply incredible that the conduct of a person's life is controlled by the configuration of a number of comparatively small material bodies millions of miles out in space. Certainly we should not believe anything of the sort without observational and statistical proof, but such is entirely wanting.

Some persons believe that the figures 1, 3 in that order are "unlucky". In the reverse order 3, 1 they must be favourable. Happily the writer's birthday was on the 31st of the month! "Rubbish!" you say? The same word applies to the following fair sample from a well-known book on astrology. Referring to the planet Mars, it says: "In the vegetable world he rules all such herbs as are *hot* and *dry*, or have sharp-pointed leaves, or that are red, and usually in barren high stony places, as the thistle, brambles, briers, nettles, onions, lingwort, radish, mustard seed, ginger, pepper, garlick, hemlock, horehound, tamarinds, etc."

Years ago the writer made a serious attempt to learn the principles or rules by which the astrologer works and tried to read some of the

books on the subject. The first difficulty in the way was the indefiniteness throughout the books. The term "house" is referred to continually but nowhere was a clear definition of it given. Similarly with other terms. Was it intentional or did the writers themselves have a clear notion of what they were talking about? An admirable paper on Astrology by Professor Alfred Baker was printed in this JOURNAL for November, 1921.

It is gratifying to note that we do not hear the voice of the astrologer over the radio or see his (or her) contributions in the press so frequently as five years ago.

From a recently published book entitled "You and Heredity" a friend sends the following quotation:

> There are many myths and superstitions, and not a few psuedo-scientific theories, regarding the influence of the sun, planets, atmospheric conditions, and various cosmic factors, on the behaviour and achievements of individuals, all implying that the person born at certain times, under certain conditions, will have such and such a personality. Regarding these, we can only say that Science offers no corroborative evidence whatever. To discuss these "influences" at greater length would be like setting up stuffed dummies for the sole purpose of promptly knocking them down again.

C. A. C.

MEETINGS OF THE SOCIETY

Elected Members-at-Large during 1939

R. H. Babbage, 4474 St. Catherine St., Westmount, P.Q.
W. P. Morse, 18 High St., Houlton, Maine, U.S.A.
Stanley E. Putnam, 3457 73rd St., Jackson Heights, N.Y.
Wilmond W. Parker, Bethel, Vermont, U.S.A.
P. O. Parker, P.O. Box 193, Ooltewah, Tennessee.
Emrys Evans, P.O. Box 666, Mountain Home, Idaho.
Frank Wickenburg, 600 Catalina Blvd., Point Loma, Calif.
David W. P. Jewitt, 2680 West Park Blvd., Cleveland, Ohio.
F. B. Marr, 1139 Southern Pacific Bldg., San Francisco.
S. Clark, Supt. Industrial School for Boys, Regina, Sask.
Wm. Brown, 8 Perth St., Guelph, Ont.
Wallace E. Evans, 1348 Magnolia Avenue, Norfolk, Va.
Rev. H. F. Schade, New Dundee Baptist Church, New Dundee, Ont.
Ivan E. Brouse, M.D., 316 West State St., Jacksonville, Ill.
Thomas J. Doran, 1417 Pacific Avenue, Brackenridge, Penna.
Elmer Reese, 241 South Mt. Vernon, Uniontown, Pa.
Frank E. Grommes, 921½ Woodbourne Ave., Brookline, Pittsburgh, Pa.
Otto Milbraud, 19131 Dean St., Detroit, Mich.
C. W. Eichhorn, 6 Everett Place, Grantwood, N.J., U.S.A.
Lewis A. Brigham, Boston University, Boston, Mass., U.S.A.
B. Leimbach, 6 Fort Hill St., Fort Fairfield, Maine, U.S.A.
H. F. Semke, Jr., 36 Nieman Avenue, Lynbrook, N.Y., U.S.A.
Victor S. Cavener, 2829 W. Park Place, Okla City, Okla, U.S.A.
George Stadel, C.E., 426 Shippan Avenue, Stamford, Conn., U.S.A.

AT TORONTO

October 3, 1939.—The first of the Autumn series of meetings of the Toronto Centre was held at the David Dunlap Observatory, Richmond Hill, at the invitation of the Director, Dr. R. K. Young. The members met in the lecture hall, Mr. S. C. Brown in the chair.

Dr. R. K. Young gave a general description of the exhibits on display and where they were to be found, after which the members were free to examine them.

Several pieces of apparatus made in the Observatory workshops were shown. In the clock room Dr. Heard explained to the visitors the essential points about the microphotometer which is for the photographic recording of the variations of intensity across spectra. Across the hall Dr. Young had his apparatus for grinding mirrors set up and running. On display near by was the Schmidt camera, the mirror for which was made by Dr. Young with this

apparatus. The minute plate holder and a spectrum of α Lyrae taken with the camera, were also shown. On the top floor two useful ways of testing the shape of a mirror were shown: the Ronchi test and the knife-edge test. A method for testing the flatness of an optical surface was also displayed. The measuring engines were set up, as when in use, to show the method used in measuring plates for radial velocities. Two enlargements of plates taken with the Newtonian camera were shown; the one was a spiral in Triangulum, the other the Dumbell Nebula. Dr. Millman had an elaborate display concerning the study of meteors. Of especial interest was the large mounting for six cameras which could be turned to any part of the sky. In front of the cameras is a rotating shutter which is run by a synchronous motor and cuts off the light from the sky twenty-five times a second. Two of the cameras have prisms mounted in front of their lenses, so that it is possible to photograph the spectra of meteors. With this apparatus Dr. Millman got direct photographs of twelve meteors and one spectrum during the Perseid shower last August. Enlargements of some of these photographs were shown, along with others from co-operating stations. A map showing the places from which reports of the Dresden Meteorite had been received, was another interesting part of the exhibit. The 19-inch telescope was operated by Mr. Tidy, the 74-inch by Dr. Hogg.

Refreshments brought to a close a very enjoyable evening.

October 21, 1939.—The regular meeting of the Royal Astronomical Society of Canada, Toronto Centre, was held in the McLennan Laboratory, University of Toronto, on October 31, 1939. Mr. S. C. Brown was in the chair.

The following were elected to membership in the Toronto Centre:

Dr. S. K. Clark,	5 Glen Cedar Road,	Toronto
Mrs. S. K. Clark,	5 Glen Cedar Road,	Toronto
Mr. C. F. Ewers,	250 Lauder Avenue,	Toronto
Mr. D. Deans Henderson,	31 Tyrrell Avenue,	Toronto
Miss Edith L. Leach,	25 MacPherson Avenue,	Toronto

Mr. Brown announced that a new book had been procured by the Library, "The Glass Giant of Palomar", by D. O. Woodbury, and with several others brought to the meeting by Miss Budd, was available for loan to the members.

Dr. Millman made an announcement concerning the HANDBOOK which will be off the press in the middle of November; for quantities of ten or more copies the price is twenty cents per copy, instead of the price of twenty-five cents for single copies. A cast of the Dresden meteorite, procured by the David Dunlap Observatory, was on display.

Mr. Brown then called upon the speaker of the evening, Mr. J. R. Collins, whose subject was "Rapidly Changing Views in Astronomy". Mr. Collins pointed out that the very early work consisted in mapping the positions of the stars and of the planets among the stars, but that since the time of Newton progress has been rapid.

Many suggestions have been made through the years concerning the origin of the solar system. All the theories have difficulty in explaining all the observed

facts. One of the earliest was Descartes' vortex theory, which started from a great nebula of gas at a high temperature. The nebular theory, first suggested by Swedenborg, was put on a mathematical basis by Laplace. Norman Lockyer conceived the solar system being evolved from a shower of meteors. The planetesimal theory was suggested by Moulton and Chamberlin. Later theories of tidal action and of collision also have difficulties in connection with them. There has also been a suggestion that the solar system was formed at the same time as all the stars in the distant past.

Great changes in our views of variable stars have developed as data accumulated. Variations were found to be due to a dark star eclipsing a brighter one and even to pulsating stars, an idea that seemed quite improbable at one time.

We are now reconciled to the idea that some stars have tremendous densities; the companion of Sirius has a density some 50,000 times that of water.

Light was thought to be simply corpuscular at one time. Newton found that the idea of a wave motion transmitted through an all-pervading medium explained such phenomena as refraction more easily. At the present time a combination of the two theories is prevalent.

Difficulty arose in the conception of gravitation due to gravity apparently requiring time to act; yet from observation it appeared to act instantaneously. This difficulty was surmounted with the advent of the idea of a field around each particle.

There has been a great deal of speculation concerning space, whether it is finite or infinite. Herbert Spencer, a nineteenth century philosopher, tried to show that the ultimate terms in scientific and religious thought to be "Unknowable". Mr. Collins concluded by pointing out that progress has gone on by people who have rejected this philosophy.

Dr. Hogg continued with his discussion of the observed celestial motions, considering in greater detail the most obvious motion, that of the stars rising in the east and setting in the west. Even 2500 years ago it was realized that there were two possible explanations: (1) the objects do rise in the east and set in the west, the earth being at rest, (2) the objects remain stationary and we, on the earth, rotate from west to east. To the ancients both were equally plausible, for the earth does appear to be fixed. We must have evidence to prove that one or the other is correct.

Dr. Hogg pointed out that the Copernican system made the arithmetic easier, but did not offer observational evidence. He then considered some observations that cannot be explained by the idea of a fixed earth. (1) The oblateness of the earth was predicted by Newton in 1686. In 1731 the shape was found to be an oblate spheroid, with the amount of oblateness equal to that predicted by Newton. (2) The eastward deviation of falling bodies is another test for a rotating earth. This was first discussed by Newton, but no good proof was made until 1830 when a mine shaft was found that was deep enough to show the effect. Further observational evidence will be discussed at the next meeting.

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